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THE CATALOGUE OF REFLECTION NEBULAE

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THE CATALOGUE OF REFLECTION NEBULAE

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ABSTRACT. The Catalogue includes 118 reflecting nebulae, for which values of the flux and dimensions are determined. The data about illuminating stars include the star magnitudes and spectral classes. On the basis of the observational material some correlations, such as correlation between the brightness of the illuminating star m and the flux from the nebula H_τ, correlation between H_τ areosop the nebulae, were investigated.

A discussion of observed correlations was made. It is shown that for all the totality of objects they can approximate the spherical nebulae. Assuming that the middle size of a cloud is R_0 = 1.5 pc, we get $\mu\tau_0$ = 0.36 for the cloud and $\mu\tau$ = 0.18 for the nebula, the albedo of the particles is $\mu \geq 0.5$.

In the annotations to the Catalogue the structure of nebulae and their connection with surrounding stars are considered. It is noted that a great deal of reflecting nebulae are connected with dark clouds. Apparently some part of these nebulae are not accidentally connected with star clusters, T Tauri stars, flash stars. A row of distributions in dependence on brightness of the nebula, spectral classes of illuminating stars, their distribution on the Galaxy longitude and latitude is investigated. It is noted that the majority of nebulae are the members of groups or associations of strom from groupings or complexes. (A69-39722)

A catalogue of reflection nebulae was compiled on the basis of material acquired in 1963-1966 with the 500-millimeter (F = 1,200 mm) Maksutov-system meniscus telescope (on Astro Special plates). Other catalogues [1, 2] and the charts of the Palomar Atlas were used to identify the nebulae with previously */3

*Numbers in the margin indicate pagination in the original foreign text.

known objects. This inspection resulted in selection of 120 nebulae. Most of them, to judge from the Palomar Atlas charts, have the type C spectra of reflection nebulae. With rare exceptions, however, the spectral characteristics of the nebulae are unknown to us. For this reason, we class objects that are distinctly visible on photographs taken in blue light, but are invisible or very faint in red light, as type C nebulae. Some of the nebulae with C + E spectra have also been included in the list for observations — namely, those which, despite the fact that they are distinctly visible in red light, are brighter in blue light or have larger photographic dimensions.

Observational Method and Instruments

One of the basic observational characteristics of reflection nebulae is a quantity that characterizes the ratio of the total flux from the nebula or the brightness at a given point on the nebula to the flux from the star illuminating the nebula. We shall henceforth refer to the star responsible for the luminosity of the nebula as the nucleus. Extrafocal photographs of the nucleus are used very frequently in observations of nebulae to standardize surface brightness or flux. However, this method has a number of shortcomings, especially when many photographs must be processed. To avoid the additional work needed to determine the transparency coefficient, it is necessary to observe the same object twice at the same zenith distance. This results in highly inefficient use of time. When the nuclei are faint, it is necessary to throw the image slightly out of focus so that it can be photometered. Photometry of slightly out-of-focus star images is burdened by large errors. It is necessary to know the magnitudes of the nuclei in order to bring out the various types of statistical relationships, and this, in turn, requires yet another set of observations. For these reasons, the observational program was broken down into two parts: observation of the nebulae and observation of the nuclei. /4

Standardization and Calibration

Star clusters with known magnitudes in the UBV system were selected for the acquisition of standardized photographic images. The simplest way to standardize areal objects is to use extrafocal star photographs. As has been shown by D.A. Rozhkovskiy [3], the best results can be obtained if the entrance aperture of the telescope is stopped down to 1:10 when the extrafocal star images are photographed. The resulting extrafocal images are quite homogeneous. The stop that we use is a black disk with four holes 120 mm in diameter. The stop was mounted directly in front of the telescope's meniscus lens. For most nebulae, the standardization photographs were obtained with extrafocal star images 0.3 - 0.4 mm in diameter. The negatives were calibrated with a tubular photometer illuminated by the night sky. In view of the considerable gradation of illumination from hole to hole, a series of impressions with slightly differing exposure times was made.

The nuclei of the nebulae were photographed in focus. The nuclei were standardized and calibrated against the focal photographs of the clusters. To avoid extremely short exposures in photographing the nuclei and the standard area, the telescope was stopped down to 1:10. This improved the quality of the in-focus star images without affecting the color characteristic of the star-magnitude system.

Observational Material

The basic observational material was acquired in 1963-1966. The exposure time limit for photography of the nebulae depended on the skyglow and amounted to 14 minutes; that for the nuclei was three minutes.

The nebulae and nuclei were photographed at the same altitude as the standard corresponding to them. One or two negatives and no fewer than two photographs for determination of nucleus magnitude were obtained for each nebula.

Photometric Processing of Observational Materials

The negatives were processed on an MF-4 microphotometer. The object of processing was to determine the integral brightness of the nebulae and nuclei. Using the results from measurement of the flashes from the tubular photometer,

we plot curves for each series of impressions with magnitude and blackening (density) as coordinates. The curves are then parallel-shifted along the stellar magnitude axis to obtain the best congruence of the curves of all series, and the final calibration curve is drawn. This curve is then used to determine $E_n + E_b + E_{au}$ in relative units; i.e., the illumination E_n produced on the plate by the nebula weighted by the skyglow E_b and the illumination E_{au} from the /5
aureole. Since we have data on the blackening due to the skyglow, we find E_b from the same calibration curve. The illumination E_{au} arises owing to scattering of starlight in the photographic emulsion. The problem of correcting for the aureole is examined in detail in [4]. Here we shall dwell only briefly on this problem. A series of auxiliary stars slightly brighter and fainter than the nucleus is selected on the focal photographs of the nebula outside the latter's limits. The photographic density of the aureole around each star is measured at various distances r from the star. Next $E_{au}(r)$ is determined. Then the brightnesses E_* of the nucleus and auxiliary stars are determined from extrafocal or short-exposure focal photographs. A sufficiently complete set of $E_{au}(r) = f(E_*)$ curves is obtained in this manner. From it, the similar curve for the nucleus is obtained by interpolation. Correction for the aureole represents no difficulty after these operations have been completed.

Without dwelling on the various data-reduction details, we feel that it is necessary to illuminate certain problems of photometry technique. To obtain the integral brightness of the nebula, it is necessary to measure it at many points and refer to the calibration curve to convert each density value obtained into an illumination. This procedure requires a great deal of time. In certain cases, the process of reducing the observations can be accelerated substantially by use of instrumental accessories. In photometry of spherically symmetrical nebulae, it is convenient to impart a precise rotational motion to the photographic plate. An appropriate turntable was mounted on the stage of the MF-4 microphotometer at the position usually occupied by the negative to be photometered. A round disk with a central aperture was rigidly secured to the inner race of a ball bearing between microscope objectives and can either be turned at high speed to obtain the average brightness distribution along the disk of the nebula or indexed through 1/60 of a revolution. We turned the disk rapidly to determine the integral brightnesses of spherical nebulae. The integral flux can be found easily from simple formulas once the average brightness distribution along the disk has been secured.

A "Floks" scaler was used to determine the integral brightnesses of large nebulae with irregular shapes.

Let us examine the calibration curve in density-illumination coordinates (Figure 1). Let us set E_b, which corresponds to the background density due to the skyglow, equal to unity. We then find E_m, which corresponds to the maximum density of the negatives photometered. In the interval $[E_b, E_m]$, we divide the E-axis into n equal parts, thus breaking up the D-axis into n unequal parts. We place a rigid black strip S on the D-axis and prick small holes into the strip at the points where the ordinates cross the D-axis. We see from Figure 1 that if we count from D_b, a certain number of holes i will correspond to a density D_i. The illumination E_i, now free of skyglow, is calculated from the simple formula

$$E_i = (i - 1)\ \Delta E.$$

Further, let the density D_i be characterized by the deflection angle α of a galvanometer mirror or by the deflection of the beam on the screen of an oscillograph. We place the black strip between the observer and the galvanometer /6
mirror in such a way that the light spot from the mirror will strike the first hole at density D_b. If we then begin to measure the density D_i, the galvanometer mirror will turn through an angle α. As it turns, the flying spot will move down the black strip, from time to time falling onto the holes. The observer will see a series of flashes. The number of these flashes determines the unknown E_i by the formula

$$E_i = (i = 1)\ \Delta E.$$

Under real conditions, a photomultiplier occupies the position of the observer, and a pulse at its output will correspond to each flash. Any pulse counter, for example, the "Floks", can be connected to count the pulses. The "Floks" has another advantage in that it can add pulses. This means that the

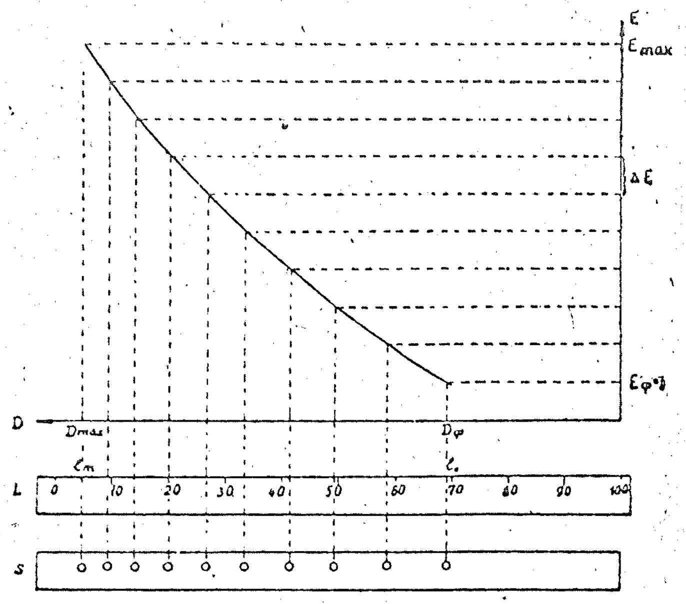


Figure 1

value of the flux appears on the display of the "Floks" counter when photometry has been completed. The system described above has a number of design shortcomings. So that the photomultiplier will be able to "see" all of the holes, it must be mounted at a considerable distance from them. The flashes may then not be bright enough to register. In principle, such a scheme should work quite reliably with a sensitive photomultiplier and an amplifier.

We use a different design in which the light source is stationary and the strip S moves in front of it. An EPP-09 potentiometer is used for this purpose. The punched strip is mounted on the potentiometer's moving carrier. A lamp is mounted in a stationary position inside the case of the potentiometer, and the photomultiplier on the outside. Obviously, photometry must consist in reading the background before each measurement at a given point on the negative. This procedure is awkward in practice, since it requires shifting the negative back and forth on the photometer between the background and the point being photometered for each measurement. Photometry is greatly simplified by taking a dark reading, i.e., simply closing the microphotometer shutter, for each density measurement. Then the entire working procedure will be as follows: /7

(1) Using the EPP-09 as a recording instrument, we measure the flash from the tubular photometer.

(2) We measure the background and the highest density on the negative. Here we obtain certain readings l_0 and l_m, expressed in millimeters, on the potentiometer scale.

(3) We construct a calibration curve in E, D-axes, setting $E_b = 1$ (Figure 1).

(4) We apply the rigid opaque strip to the D-axis.

(5) We divide the E-axis into n equal parts on the interval $[E_0, E_m]$. The number n depends on the number of holes that can be pricked in the strip, with the condition that the light source illuminate no more than one hole at a time. In our measurements, n was 20.

(6) We set the EPP-09 potentiometer carrier to position 1_m, which corresponds to the maximum-density reading. We then secure scale S to the carrier to the left of the light source in such a way that the hole corresponding to D_b will be opposite the lamp.

After all of these operations, we can proceed to the actual photometery. The illumination E_i is computed by the formula $E_i = n\ (n - i)\Delta E$. The number i is registered with the "Floks", and n is given for a given calibration and equals the number of holes in the strip. The formula for determination of the nebula's integral brightness is easily derived:

$$H_n = \Delta S \Sigma\, (n - i)\, \Delta E = \Delta S N n \Delta E - \Delta S \Delta E \Sigma_i, \qquad (1)$$

where N is the number of points measured, Σ_i is put out on the "Floks" display as the result of all measurements, and ΔS is the unit area defined by the unit shift of the negative during photometry.

Accuracy of Results

Nonconformity of our color system of magnitudes to the B-system may be a prime source of error. In Figure 2, magnitudes in the B-system are plotted against the axis of abscissas, and the magnitudes that we determined for the same stars from extrafocal star images are plotted as ordinates. Figure 2 indicates that our system of magnitudes is in good agreement with the B-system from

5^m to 12^m. The mean-square error σ_* in determination of stellar magnitude from a single star image is $\pm 0^m.13$. Since the brightnesses of the nebulae were found from an average of five stars, the error in determination of the nebular magnitudes is $\sigma_n = 0^m.07$. Considering the other possible error sources, we can write $\sigma_n \approx 0^m.10$.

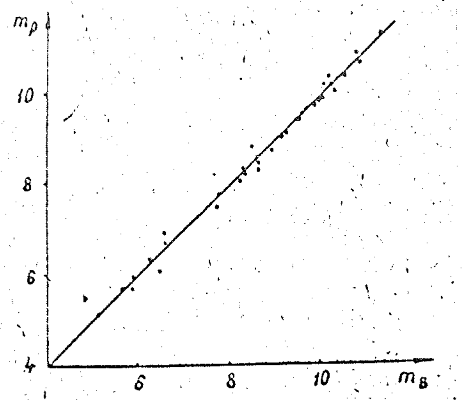


Figure 2

Explanatory Notes to the Catalogue /8

The catalogue contains photometric, morphological, and certain other data for 118 objects. The overwhelming majority of these objects are "typical" reflection nebulae in whose emission the H_α lines are either altogether absent or much fainter than the emission in the photographic region of the spectrum. A certain number of the nebulae have the characteristic C + E spectrum, i.e., they are equally visible on photographs taken in photographic and H_α light. For the most part, these are peculiar objects whose structure may differ substantially in "red" and "blue" photographs, which often have extremely high integral brightnesses, etc. Such objects merit more thorough investigation. The corresponding sources are indicated in the remarks. The catalogue does not include very faint large-area nebulae associated with bright stars at apparently short distances from us. Without special observations, e.g., polarimetry, it is impossilbe to give a definite indication as to the corresponding nuclei. Detailed data on the nebulae in the Pleiades, which form a rather intricate complex of possibly interrelated objects, have also been omitted from the catalogue.

On the whole, the catalogue includes practically all nebulae with $\delta > -25°$, diameters of at least $0'.3 - 0'.5$, and nuclei no fainter than the 15th photographic magnitude, i.e., all objects accessible to the 500-millimeter Maksutov meniscus telescope.

As compared with Cederblad's summary [1], the catalogue contains more than 30 new objects [5], but it excludes the emission nebulae identified by Cederblad as reflection nebulae or nebulae of the mixed C + E type.

All data on the nebulae and the stars that excite them are tabulated in the catalogue in the following scheme.

Column 2. The designation of the nebula, with the conventional NGC or IC numeration or numeration according to Cederblad's catalogue.

Column 3. The HD or BD number of the exciting star or nucleus.

Columns 4-7. The coordinates of the nucleus if known; otherwise the coordinates of the nebula. The relationships $l_1 = l_{11} - 33°$ and $b_1 = b_{11}$ are adequate for rough conversions to the old galactic coordinates.

Columns 8-9. The spectral class and magnitude of the nucleus on a scale closely similar to the Johnson-Morgan B-magnitudes.

Column 10. The integral brightness of the nebula expressed in stellar magnitudes. Sometimes the average surface brightness ν is cited.

Column 11. The average brightness of the night sky (background), expressed in stellar magnitudes from one square minute, at which the object under study was photographed.

Column 12. The figures given here determine the size of the area for which the integral brightness m_n was found, in minutes of arc.

Columns 13-14. The maximum angular distance at which the nebula is still visible. For spherical nebulae, the maximum angular distance is the same as the radius within which the nebula's integral brightness was found.

Column 15. The integral brightness of the nebula, expressed in units of brightness of the nucleus.

Column 16. Distances to the nebulae, taken for the most part from Cederblad's catalogue.

Column 17. Certain additional data on the individual objects. For example, there are references to apparent shape: S indicates a spherical /9
shape (a nebula with a more or less symmetrical decrease in brightness from the nucleus toward the periphery); K indicates a comet-like object (the shapes of such objects may vary widely; I_r is an irregular nebula that admits of description with difficulty; E_x indicates nebulae that are outside of their nuclei, even though they may have regular outlines (this class also includes those nebulae for which identification of the exciting stars is difficult).

A considerable number of the nebulae are, apparently at least, situated in dark-cloud regions. Many of them appear as quite isolated formations. The apparent relationships with the clouds are indicated by the following symbols: 1 - nebula inside cloud; 0.5 - on margin of cloud; 0 - no clear association /10
with a cloud.

The lack of spectral data on the nebulae makes it impossible to classify the objects by color characteristics. We obtained a rough classification by visual estimates made on negatives obtained in blue and red light: C indicates a nebula whose emission in the red is either altogether absent or noticeably weaker than its emission in the photographic region; C + E indicates a nebula that is equally visible in blue and red light; C, E stands for a nebula whose shape and structure are quite different in blue and red light.

Each of the drawings accompanying the catalogue (Figures 3 - 10) indicates the relative positions of a cloud and the nebula (or group of nebulae) associated with it. The drawings reproduce the content of our photographs and that of the reproductions in the Palomar sky atlas. The scales are the same. /11

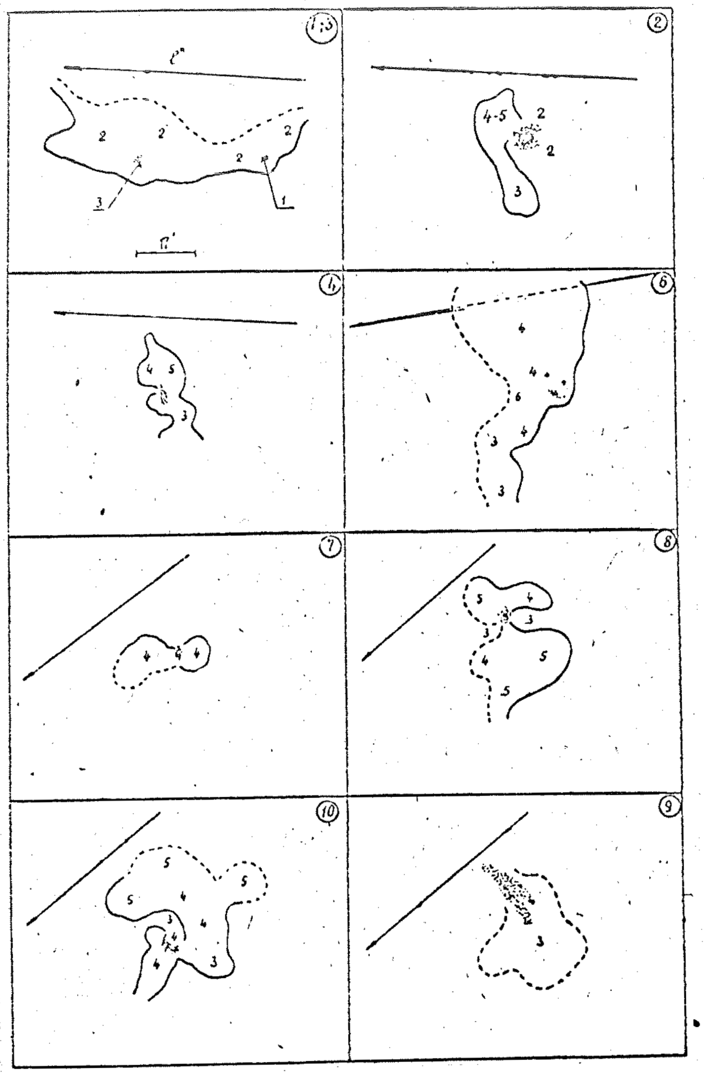


Figure 3

Numerals from 1 to 5 give a rough estimate of the absorption by the clouds on the Lynds scale [6]. In certain cases, the data used are taken directly from this source. Each unit on the scale corresponds to an absorption approximately equal to one stellar magnitude. In most cases, however, this scale was used only as a prototype for estimation of the unknown absorption of the particular cloud.

A number of important reservations must be stated here. First, the visibility of a dark cloud and the judgement as to whether it is actually present at a given position depend extremely heavily on the density of the star background and its natural fluctuations. Clouds with strong absorption are almost always identified quite reliably on the basis of a number of criteria: sharpness of margins (which are sometimes faintly luminous), the absence, in the particular region of the sky, of star-background-density fluctuations that might simulate a cloud, the visibility of faint gal- /12
axies, and so forth. In most cases, the contours of such clouds have been represented on the drawing without taking any special liberties. More license is naturally required in determination of boundaries and absorption in clouds of low and medium density seen against strongly fluctuating and sparse star fields. Here the absorption estimates may be on the high side, since an accidental star-density defect may be ascribed to absorption. Something similar is

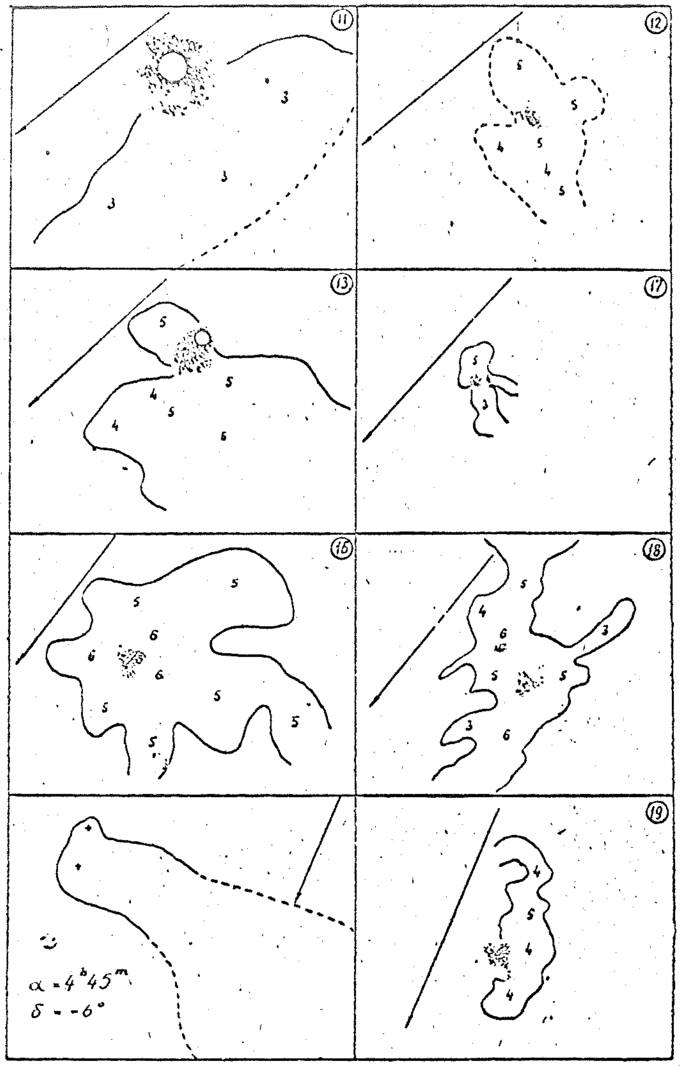


Figure 4

observed in the regions of the Milky Way that are occupied by extensive dark clouds of complex structure. Here, however, errors are less likely. A clear overestimation of absorption may occur in regions remote from the galactic equator, where the density of stars drops sharply. The result is a kind of "Hagen error", but one of a totally different nature [7].

In doubtful cases, the cloud outlines are indicated by broken lines on the drawings. In some cases that are at first glance doubtful, it is still possible to establish the reality of the association between the reflection nebula and the absorbing medium. We refer here to globules, dark lanes and condensations "embedded" directly in the structure of the nebula itself, even though the latter does not belong to a definite dark cloud. In such cases, it is logical to estimate absorption higher on the scale, even though the justification for so doing is not complete. /13

It must be acknowledged that the information given in the catalogue is incomplete primarily as regards the spectra and luminosities of the reflection-nebula nuclei. At the same time, both these data and data on the color excesses of the nuclei and the polarization of their light, the spectral polarization properties of the nebulae themselves, etc., are absolutely necessary for determination of distances and solution of other problems of fundamental importance

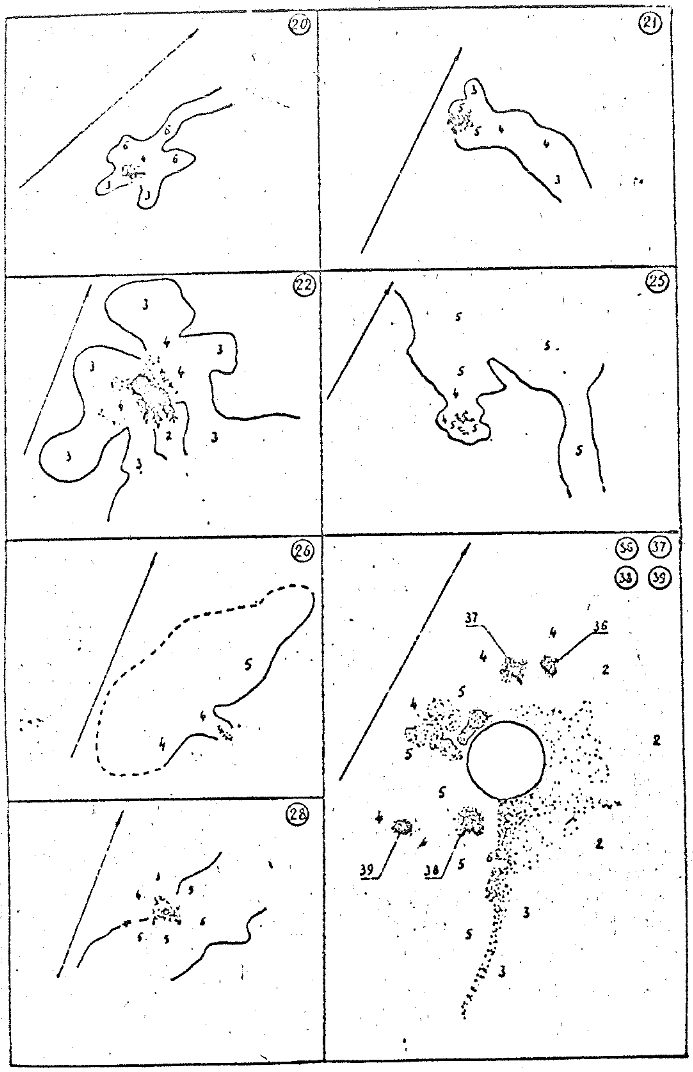


Figure 5

(for example, for judgements as /14
to the properties of interstellar dust particles, random association of hot stars with dark clouds, etc.). Briefly, the listing of reflection nebulae and the stars corresponding to them merits more careful and complete investigation. Most of the problems enumerated here present no particular difficulty for modern, well-equipped observatories and will, in all probability, be solved during the next few years. From this standpoint, the catalogue published here may be regarded as the beginning of this task.

We describe the individual objects listed in the catalogue:

2 - situated on the margin of a compact cloud associated with three bright stars whose total magnitude is $6^m.52$. The nebula consists of a bright nucleus and a peripheral part. The bright region is 1'.5-2' across. There are two /15
variables in the vicinity, one of which is RW Aur;

4 - on the margin of the open cluster NGC 255;

5 - in addition to this nebula, five more small nebulae (∿0'.1) are observed;

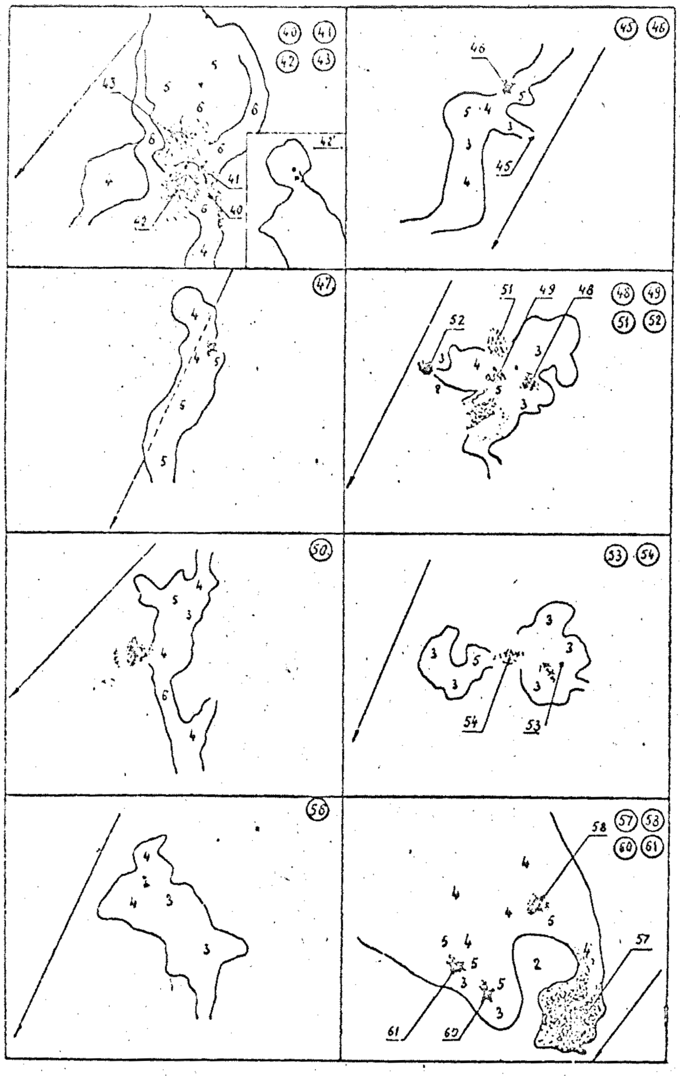


Figure 6

6 - the reflection nebula has companions with the C + E spectrum, characteristic dark gulfs, and rims that indicate exciting stars;

9 - faintly visible in red light; structure the same in C and E;

11 - a type UG variable in the vicinity;

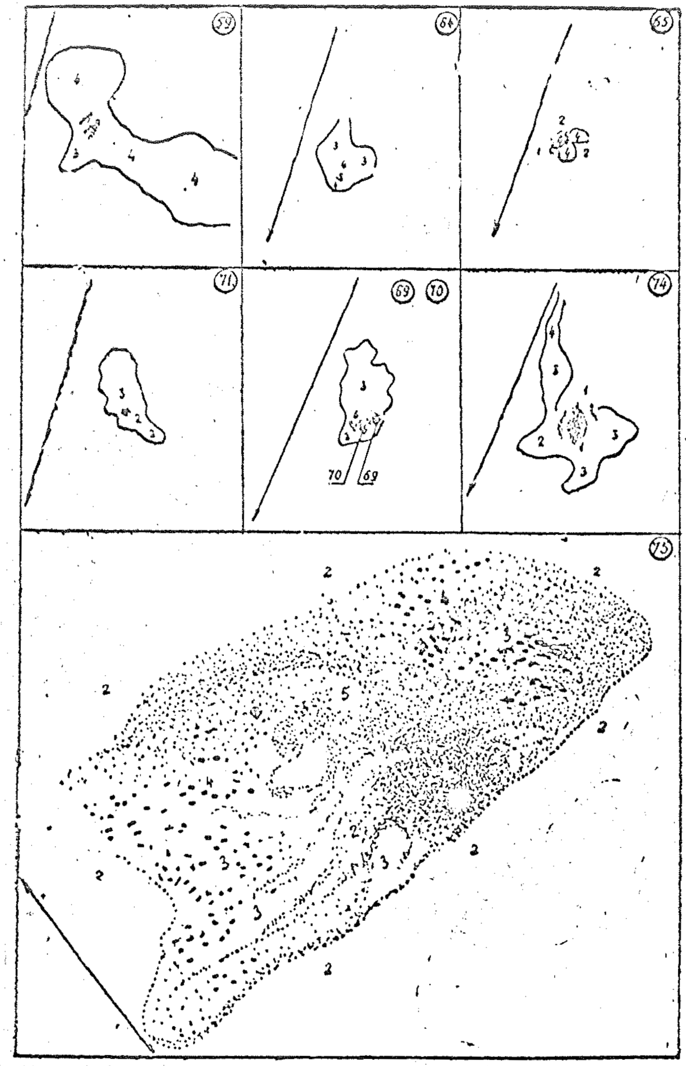
12 - toward the southwest, the nebula undergoes a transition to E and concentrates around another star. According to M.V. Dolidze [8], there are two stars with H_α emission in the immediate vicinity; these may be part of the Per II association. N.N. Johnson [9] gives for the nebula

$$B-V=+0^m,96, U-B=-1^m,10.$$

There is a faint variable star of the type In on the edge of /16
the cloud type in variable on the margin of the cloud. According to Martel [10], the polarization indicates association with the stars BD 30°549 and BD 30°548. A chain of small emission 15
condensations is observed:

13 - associated with the IC 348. In the cloud, and variable star Rwn — the center of a T-association [20];

14 - cluster of nebulae in the Pleiades (see article by Yu. I. Glushkov in this collection;



'Figure 7

15 - a small emission nebula around the nucleus in E. In C, the nebula is situated to one side of the nucleus. A group of type Rwn variable stars in the vicinity of the nebula;

16 - N.N. Johnson [9] reports two variable nuclei, DD Tau, CZ Tau, with spectral classes dK6e and dM2e;

17 - the nucleus is the variable RY Tau;

18 - reflection nebula belonging to the group of emission and C + E objects. Two 16^m variables of unknown type; /17

20 - situated at the end of a lane that terminates in a strongly absorbing compact cloud with R = 12'. The nebula takes the form of a dense aureole with r = 1'. The nucleus is variable star RWn of the type AB Aur;

21 - associated with a tight group of stars. One of them is an emission star [8];

25 - cometary. Faintly visible in red light. Structure very closely similar to that of NGC 2068. Part of the nebula is separated from the main body by a strongly absorbing bridge;

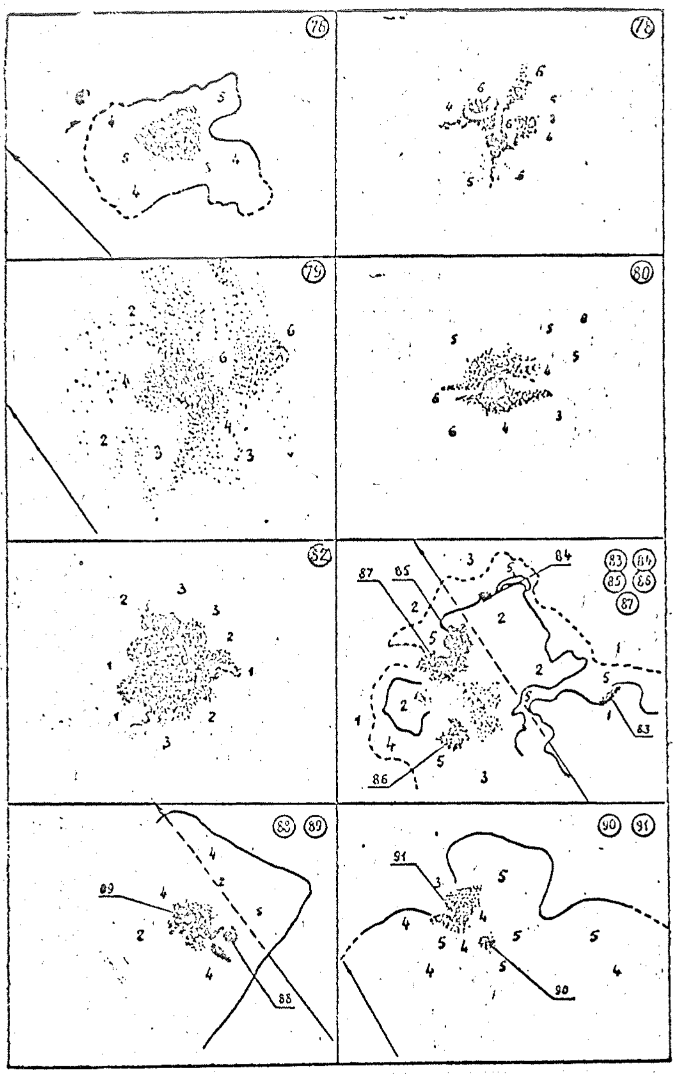


Figure 8

28 - a type RWn variable in the immediate vicinity of the nucleus;

29 - no nucleus. Faintly visible in E;

30 - no nucleus. Faintly visible in E;

31 - cometary, discernible in E. Source of luminosity not definitely determined. Possibly a star in the head of the comet;

34 - the nucleus is ω Ori; according to the CSP [Katalog Polozheniy Zvezd (Catalogue of Star Positions)], possibly a variable;

36 - the luminosity of this nebula was studied by D.A. Rozhkovskiy [4];

37,38 - data published in this collection;

39 - data published in [4];

42 - data published in [9, 11]. Variable stars and Herbig-Aroult objects are visible;

40,41 - nebulae separated from NGC 2068 by a dark bridge; apparently, this is part of NGC 2068;

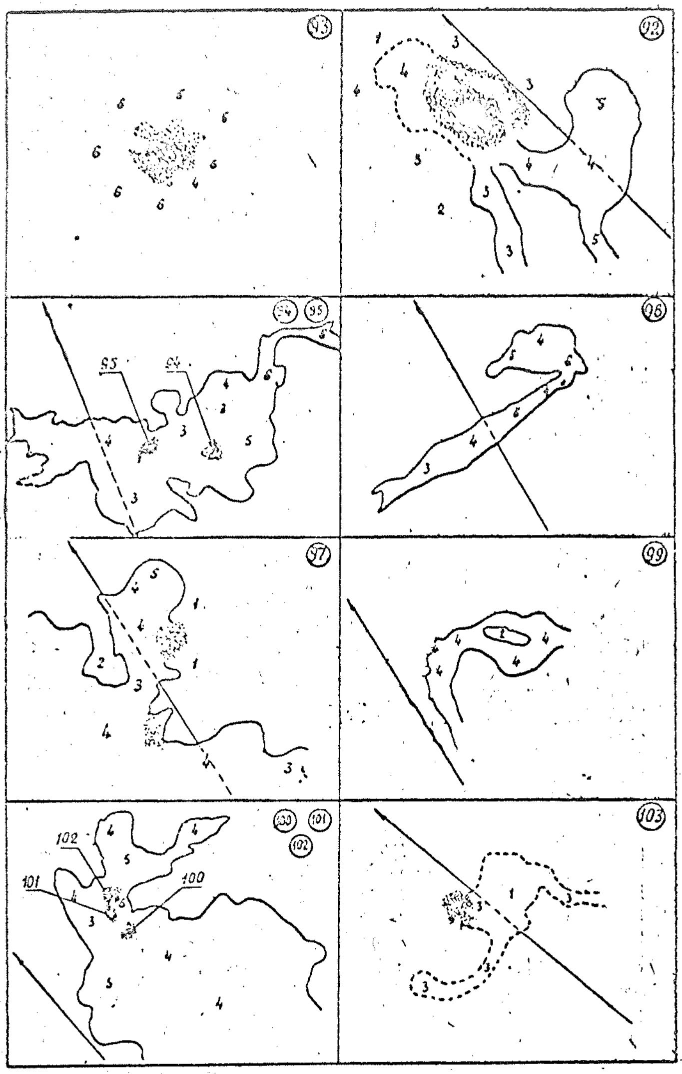


Figure 9

45 - possibly an emission nebula. A cometary tail appears in E.

44 - takes the form of an extremely compact condensation around a nucleus with r = 0'.1 - 0'.2. The width of the entire nebula is $\sim$0'.3. The data for m_n are unreliable. Associated with a star cluster;

48-54 - a whole group of 15 C and C + E nebulae of various sizes;

49,50 - different structures in C and E; 48, 52 have a steep brightness gradient;

55 - attended by a group of small faint nebulae; no definite absorbing cloud;

57,58,60,61 - these may form a single physical grouping related to the Monoceros association. 57 has a bright central area with r = 0'.9 (the shape is different in E); 58 is associated with the open cluster Cr 95; 60 is cometary, with a bright central condensation with r - 1'.2; 61 has a bright central condensation with r = 1' 2;

59 - related to an extremely close cluster;

63 - related to a star cluster; a star of $14^m.2$ surrounded by a small nebula with r = 0'.3 is situated near the main nebula;

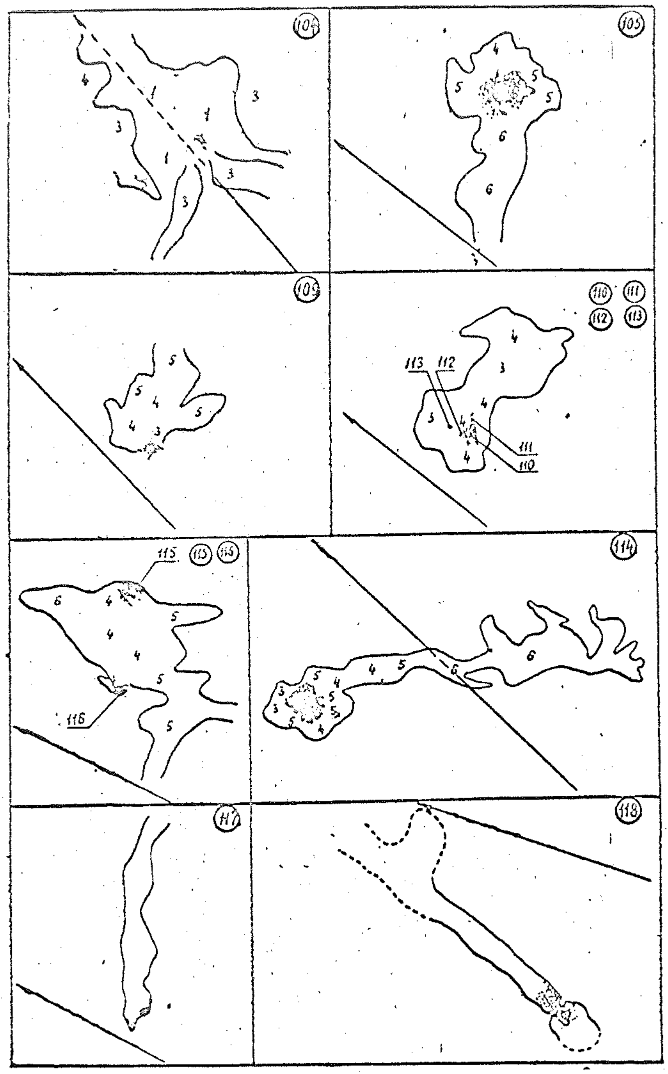


Figure 10

64 - at the center of the nebula, an extremely tight cluster of faint stars. The two close nuclei resemble diffuse objects even at 1:10 aperture ratio. Toward the north, one more small reflection nebula is observed;

65 - C + E, associated with a tight group of stars. Alongside, a very small faint nebula;

66 - related to a tight star cluster;

68 - E > C;

69,70 - form a close double;

71-73 - possibly related to a cluster of fainter stars;

75 - visible in E. Contours coincide in C and E. Two variables in the region of the nebula; AN Sco, a type RWn, and W Sco, a type M. The boundary of the nebula coincides with the boundary of the absorbing region; /18

76,77 - two close double stars illuminating a single nebula. Data on polarization given in Martel's paper [10];

78-80 - a group of nebulae, three of which are bright and situated in a lane radiant. 78 may be associated with a star group; its nucleus has a large color excess $E_1 = +0^m.50$. The type RW_n variable V 852 also occurs here. The light of the nucleus is polarized in the long direction of the lane [9]. 79 is a cluster of three stars with very strong condensation toward the center; the nucleus, ρ Oph, is the center of a T association;

81 - alongside the nucleus, the type RR Lyr variable V 743;

82 - some information on the nebula given is in [12]. A number of non-stationary stars in the vicinity of the nebula;

83-86 - a region with strong absorption and dark lanes. C + E and E objects observed along with the C. A number of nebulae are, in turn, related to close star clusters. It appears that the entire complex is a single physical group;

88,89 - the western boundary of the cloud is very sharply outlined. The nebulae are related to a star cluster;

89 - discernible in E; a dense-globule inclusion is observed;

91 - the nucleus may be a variable;

92 - situated at the junction of two lanes. Data given in the papers of Martel [10] and D. A. Rozhkovskiy [4]. Nucleus polarized in the direction of the filametnts and the long direction of the dark cloud [9];

93-98 - in the region of the Great Fork of the Milky Way;

100 - consists of a series of small, faint nebulae;

103 - nucleus surrounded by a star cluster. Dense, dark inclusions are observed on the boundary of the nebula;

104 - alongside ($\alpha = 21^h 01^m, 5$, $\delta = 50°$), a group of very small compact reflection nebulae situated in a lane;

105 - associated with a group of faint variables, flare, and T Tau stars. More detailed data are published in the present collection;

106 - the nucleus is a spectral triple of type E II, HD 203025;

108 - according to Hall [13], the light of the star is polarized in the direction of the nebula's filaments;

109 - photometric data available in [4];

110-113 - associated with a cluster of at least 10 stars;

112 - data given in Herbig's paper [14];

114 - visible near the C + E nebula IC 5146. The entire region is situated at the end of a lane. A large group of nonstationary objects also occurs here;

115,116 - margin of cloud luminous;

117 - associated with the terminus of a very dense narrow lane. The lane has faint luminosity in C and E;

118 - lane is luminous, C > E. Nebula at end of lane.

Data on the nebulae and their illuminating nuclei are given in the catalogue. A number of relationships were derived on the basis of the results.

The relationship between the brightness n_* of the nucleus and the distance
φ_n from the nucleus to the faintest point of the nebula is shown in Figure 11.
The circles indicate nebulae with spherical shapes, and the squares irregular nebulae. /19

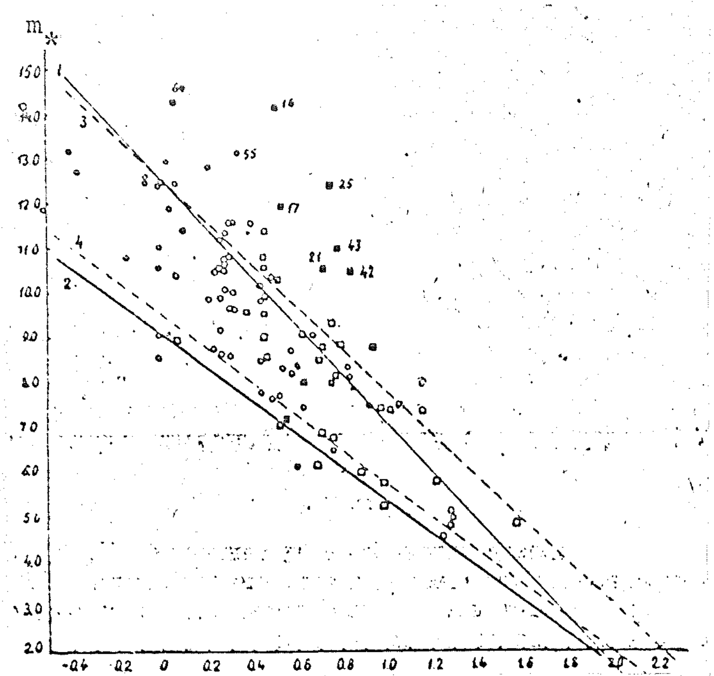


Figure 11

We see from Figure 11 that there is no distinct relationship between m_* and log ϕ_n. In linear approximation, this relationship might be given by

$$m_* = -k \lg \varphi_n + a, \tag{2}$$

where

$$k = 5{,}2 \pm 0{,}3,\ a = 11{,}5 \pm 0{,}1.$$

In the work of several other authors [1, 15-17] who have also presented m_* as a linear function of log ϕ_n, the coefficient a takes on a wide variety of values ranging from $11^m.0$ [17] to $12^m.0$ [16]. These discrepancies can be explained by a certain indeterminacy in the evaluation of m_* and ϕ_n and by the selection of the material for study. At the same time, despite the fact that there exists a definite relationship linking m_* and log ϕ_n, the scatter of the points in Figure 11 is rather wide, and may amount to several stellar magnitudes for a given ϕ_n. Clearly, such scatter cannot be explained in terms of errors in the determination of m_* and ϕ_n. Differences in the sky background on different negatives introduce a certain inhomogeneity into the material studied. It is difficult to correct accurately for the influence of sky background on nebula dimensions, owing to the irregular structure of the nebula and our lack of knowledge concerning brightness distribution in the unobserved part. We did have at our disposal negatives each of which showed a whole group of nebulae. Analaysis of these objects indicates that the dispersion in (2) remains large even at a constant night-sky background brightness ν_b. We also investigated for a possible relationship between ν_b and ϕ_n. According to our data, there was no discernible correlation between ν_b and ϕ_n. This suggests that the dispersion observed in m_* as a function of log ϕ_n is real, and not the result of reduction of the observational data. Relationship (2) is discussed in greater detail below. Here we /20

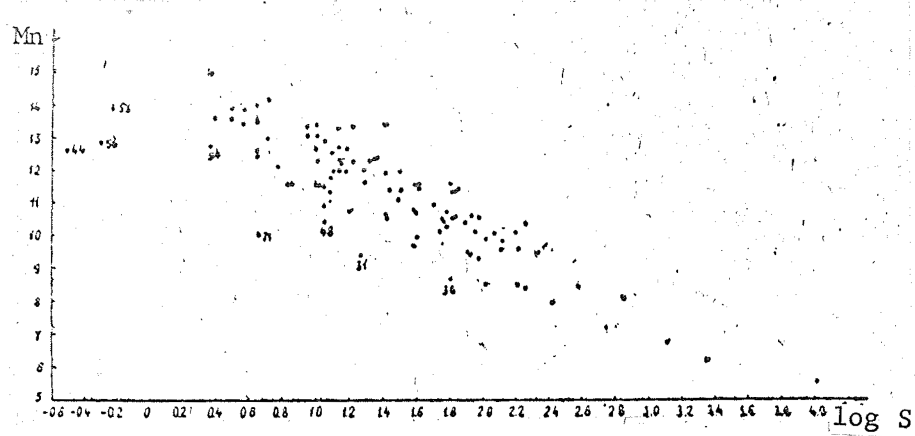


Figure 12

note only a series of nebulae not described by (2). As a rule, such objects are peculiar in some respect: they are either illuminated by several stars, or are cometary, or are unusually bright.

These nebulae include 16, 17, 21, 25, 42, 43, 55, 64, and a number of others. The properties of these nebulae are cited in the explanatory notes to the Catalogue.

Figure 12 shows the relationship between the flux H_n from the nebula and the area S from which the flux was determined.

As we see from Figure 12, the observed dependence is nicely represented by the linear relationship

$$m_n = -k_1 \lg S + \nu, \qquad (3)$$

where $k_1 = 2{,}5$, $\nu = 14{,}7$.

The coefficient ν characterizes the average surface brightness of the nebula from $1\square'$. Indeed, if we assume that the average surface brightness

$$\nu = -2{,}5 \lg \frac{H_T}{S} \qquad (4)$$

is the same for all objects, (3) follows directly from (4).

Thus, knowing the linear relationship between m_n and log S, we arrive at the conclusion that the average surface brightness of the nebulae is a constant. Needless to say, there are also substantial deviations, e.g., in 2, 31, 44, 56, and a number of others. As a rule, such objects exhibit various peculiarities that are not inherent to "typical" reflection nebulae. For example, nebula 31 is cometary, and the source of excitation has not been definitely identified.

At the same time, the close correlation between m_n and log S that follows from Formula (18), which will be derived in the next section, suggests that $\mu\tau$ does not depart greatly from the average for the majority of reflection nebulae.

Relationship (2), which we derived from the observational data, was first derived theoretically by Habbl [15], and takes the form

$$m_* = -5 \lg \varphi_n + a \qquad (5)$$ /21

(ϕ in minutes of arc).

Habbl determined a from observational data. At the brightness limit $E_n{}^n = 14^m.36$ from 1 □′ and $a = 11^m.02$.

Relationship (5) is easily derived on the assumption of uniform spatial distribution of the dust in which the stars are immersed. This takes account only of information from a small volume lying along a radius extending from the star perpendicular to the line of sight.

A number of authors [1, 16, 17] report that this relationship is, on the average, satisfied. However, observational data indicate that the scatter is nevertheless large. Moreover, this scatter cannot be explained by the observational errors. The coefficient of log ϕ_n is found to be somewhat larger than five, in contradiction to Habbl's theoretical calculations.

One possible reason for the rather indistinct dependence of m_* on log ϕ_n may be the cloud structure of the interstellar medium. Individual clouds

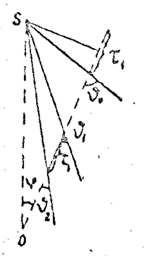


Figure 13

situated at the same distance from the star illuminating them may be observed at widely different angular distances from the star. The relation between m_* and $\log \phi_n$ may be thrown off sharply by interstellar cloud structure. It must be noted, however, that the probabilities of observing a given cloud at different angular distances from the star are different, with the result that there is an evident correlation between m_* and $\log \phi_n$.

The luminosities of a nebula of arbitrary shape at an arbitrary position relative to the star were calculated to explain the observed correlation between m_* and $\log \phi_n$. Approximate account was taken of first-order scattering in these calculations.

Let a column of dust of optical density τ_1 lie on the line of sight (Figure 13); then the brightness E_n from a square minute is determined by the formula

$$E_{n} = \frac{E_* \mu \tau_1 \mathrm{tg}\,\vartheta_0}{N \sin\varphi} \int_{\vartheta_2}^{\vartheta_1} \frac{x(\vartheta)}{4\pi} d\vartheta, \tag{6}$$

where E_* is the apparent brightness of the star, N is the number of square minutes in one steradian, and μ is the albedo of the particles.

$$\cot\vartheta_1 = \cot\vartheta_2 - 2\cot\vartheta_0. \tag{7}$$

All calculations were made for two scattering indicatrices:

$$x(\vartheta) = 1, \tag{8}$$

$$x(\vartheta) = \frac{c_1}{1 - x_1 \cos\vartheta} + c_2 \cos\vartheta \tag{9}$$

with the parameter values $c_1 = 0.394$, $c_2 = 0.666$, $x_1 = 0.987$. This last indicatrix is very close to the scattering indicatrix used by I.N. Minin [18] for analysis of reflection-nebula luminescence. The figure obtained directly from our photographs was $E_n{}^n = 15^m.3$ from $1\square'$, or 5 - 10% of the skyglow.

Here and below, the index "n" characterizes the limiting values of the parameters of the nebula, at which the surface brightness comes to $15^m.3$ from /22

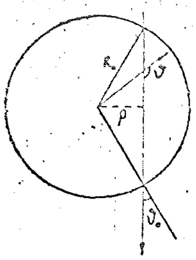


Figure 14

1□′.. Using data calculated by Formula (6) for the $\mu\tau_1$ intervals from 0.5 - 2.0 and 0.1 - 0.5, ϕ_n was found as a function of m_*. The calculated results are presented in Figure 11 in the form of averaged straight lines. Lines 1 and 2 (for a spherical indicatrix) and 3 - 4 (for a prolate indicatrix) correspond to the $\mu\tau_1$ intervals from 0.5 - 2.0 and 0.1 - 0.5. Since only single scattering was taken into account in the calculations, $\mu\tau = 0.5 - 2.0$ represents a certain parameter rather than a real quantity. For example, with $u < 0.7$, an increase in τ above 1.0 does not result in an increased brightness of the nebula. For $\mu < 0.7$, therefore, the parameter $\mu\tau$ that we use must not exceed 0.6. With increasing μ, this restriction relaxes, and at $\mu = 1$ an increase in τ always results in a brightness increase, although this change takes place slowly at large τ.

Since we find from the observations that $\mu\tau_1 < 2$, we should naturally expect most of the points in Figure 11 to fill the entire space to the left of curves 1 and 3. On the other hand, the existing correlation between m_* and $\log \phi_n$ becomes understandable on the basis of the probability of observing a cloud at a given angular distance from the star. Obviously, the probability of finding a cloud in this volume of space is proportional to the volume itself. Let us take the total volume in which the particular star can cause the observed luminescence of a cloud as unity. For a 4^m star, this corresponds to $\phi_n = 40'$. It is easy to calculate the fraction of this volume corresponding to angular distances $\phi + \Delta\phi$. For example, for the indicatrix (9) and for $m_* = 4^m$, 3% of the volume falls to angular distances ϕ_n from 1 to 10' and 97% of the interval of ϕ_n from 20 to 40'. Quite naturally, the overwhelming majority of nebulae associated with 4^m stars will have ϕ_n in the w0 - 40' range. The ϕ_n were found for magnitudes to 10^m. The agreement with observations was good. Moreover, the indicatrix of (9) or a slightly less prolate indicatrix offers, on the average, a better explanation for the correlation (Figure 11) than does a strongly prolate indicatrix.

In our earlier discussion of the deviation of the m_*-$\log \phi_n$ curve from Habbl's relationship, we succeeded in showing that, on the average, the nebulae are characterized by highly nonuniform mass distributions and slightly prolate indicatrices.

Representing the entire population of nebulae by a certain homogeneous spherical model, we can draw certain further conclusions as to the average value of $\mu\tau$.

In the general case, considering that nebulae with both small and large optical thicknesses are observed, the brightnesses of such objects should be calculated with consideration of higher scattering orders. Such calculations were carried out by A.V. Kurchakov and are published in the present collection. But on the other hand, the number of nebulae with large observed fluxes is small, and Habbl's relationship is satisfied only approximately, since the nebulae themselves have an irregular structure. All this gives reason to hope that we may be able to use an approximate calculation of the first scattering order instead of the complex calculations needed to obtain the statistical average value of $\mu\tau$ — the more so since, as will be shown below, the average value of $\mu\tau$ is found to be small ($\sim$0.18).

Let us consider a spherically symmetrical nebula of radius R_0 (Figure 14) with a star of luminosity L at its center. We shall approximate only single scattering. Then the intensity of the emission emanating from the nebula at a distance ρ from the center of the disk is given by the Formula (19) /23

$$I(\rho)=\frac{L\mu\alpha}{16\pi^2\rho}\int_{\vartheta_0}^{\pi-\vartheta_0} x(\vartheta)d\vartheta, \tag{10}$$

where $\mu\alpha$ is the volume coefficient of scattering. Accordingly, the brightness E_n of the nebula from one square minute at an angular distance ϕ from the center of the disk will be written

$$E_n=\frac{E_*\mu\tau_0\sin\vartheta_0}{N\sin 2\varphi}\int_{\vartheta_0}^{\pi-\vartheta_0}\frac{x(\vartheta)d\vartheta}{4\pi}. \tag{11}$$

Here E_* is the apparent brightness of the star, N is the number of square minutes in a steradian, and $\tau_0 = \alpha R_0$ is the optical radius of the nebula. Since the angular dimensions of the nebulae are always small, we can write

$$E_n = \frac{E_* \mu \tau_0 \sin \vartheta_0}{(\varphi')^2} \int_{\vartheta_0}^{\pi - \vartheta_0} x(\vartheta) \frac{d\vartheta}{4\pi}. \tag{12}$$

Let us consider the case in which $x(\vartheta) = 1$. Then Expression (12) is rewritten

$$E_n = \frac{E_* \mu \tau_0}{4\pi \varphi \varphi_0} \left(\pi - 2 \arcsin \frac{\varphi}{\varphi_0} \right) \tag{13}$$

(ϕ in minutes of arc),

where $\varphi_0 = \frac{R_0 \sqrt{N}}{\Lambda}$ is the angle subtended by a cloud of radius R_0 at $\varphi_n < \varphi_0$, as is usually the case:

$$\arcsin \frac{\varphi_n}{\varphi_0} = \frac{\varphi_n}{\varphi_0}. \tag{14}$$

Then it follows from (13) that

$$\lg \varphi_n = -\lg \left(\frac{4 E_T^n \varphi_0}{\mu \tau_0 E_*} + \frac{2}{\pi \varphi_0} \right). \tag{15}$$

According to Lynds [6] and our own statistical analyses, the average dimension of the cloud is given by $R_0 = 1.5$ parsecs. It follows from the catalogue that the average absolute magnitude of the nuclei $M = -0^m.5$, and from Expression (5) that a = 11.5 and $E_n^n = 2.512 - 15.3$.

Substituting the data obtained into Formula (13), we find that $\mu\tau_0 = 0.36$ for the entire cloud. And since this gives $\frac{\varphi_n}{\varphi_0} = 0.5$, we have $\mu\tau = 0.18$ for the nebula.

We have still another possible way to estimate the average $\mu\tau$ of the nebulae. If the entire population of nebulae is represented by a spherical model, the integral brightness H_n of the nebula will be determined by the following /24 formula in our scattered-light approximations:

$$H_n = H_* \mu\tau, \tag{16}$$

and the average surface brightness is

$$E_n = \frac{E_* \mu\tau}{\pi \varphi_n^2} \tag{17}$$

or

$$\nu_n = m_* + 5 \lg \varphi_n - 2{,}5 \lg \frac{\mu\tau}{\pi}. \tag{18}$$

Observations gave $\nu = 14.7$ [see (3)].

Considering that $m + 5 \log \phi_n = 11.5$, we find $\mu\tau$, which equals 0.16.

The good agreement between the values of $\mu\tau$ obtained by the different methods gives reason to assume that the entire body of observed data can be represented not too badly by a spherical model with a cloud radius $R_0 = 1.5$ parsec, $\mu\tau_0 = 0.36$, and $\mu\tau = 0.18$.

While it can be estimated from the catalogue data that the indicatrix is no more prolate than that of (9), it is difficult to estimate μ because of the smallness of the values $\mu\tau = 0.18$ and $\mu\tau_0 = 0.36$ that were obtained for the nebula and the cloud, respectively, with $R_0 = 1.5$ parsecs. For small $\mu\tau$, μ and τ are nearly equivalent in importance. They can be separated only by calculations for a homogeneous spherical nebula using highly accurate data for the flux and brightness distribution over a disk of the nebula.

Naturally, this is impossible for an average model that describes all of the statistical material. At the same time, if we assume that μ does not vary greatly from cloud to cloud, we can estimate it by examination of individual deviations from (11) and (13). Some of the nebulae mentioned above as not conforming to (2) and (3) have values of $H_n \simeq H_*$. Examples are objects 12, 17, 25, 31, 48, 56, and others. We used the results of exact calculations of spherical nebula luminescence for analysis of such nebulae.

By using the calculated data for the fluxes from the nebulae, and their observed average characteristics: $R_0 = 1.5$ parsecs, $M = -0^m.5$, and $E_n{}^n = 15^m.0$, we can easily arrive at the following conclusions: firstly, with $H_n/H_* = 0.5 - 1.0$ and $\mu = 0.5$, the radius of the luminous part of a dark cloud, i.e., a nebula, amounts to less than 0.3 of the total radius of the cloud; secondly, a nebula for which $H_n/H_* = 0.5 - 1.0$ and $\mu = 0.7$ will have a dimension equal to half of that of the entire cloud.

At the same time, it is known from observations that the dimensions of most nebulae with $H_n/H_* > 0.5$ are no less than half that of the cloud, and this, in turn, signifies that $\mu > 0.5$ for such objects.

A General Survey of the Aggregate of Reflection Nebulae

Almost all of the observational information that can be obtained on reflection nebulae is material for the statistician. Use of the exact theory, e.g., to interpret the luminescence of individual objects, which are, as a rule, irregular and peculiar, yields limited and frequently ambiguous results. The various statistically codified characteristics of the nebulae have greater weight, for example, for determination of certain optical properties of dust particles, but even then they are found to be inadequate for solution of such a problem. There are not enough objects suitable for this purpose among the total number of 200 - 250 known nebulae. /25

Although we do not now have material covering all nebulae, including objects in the Southern Hemisphere, interest will neverthless attach to certain data that proceed from the catalogue and characterize the nebulae in the aggregate in the part of the Milky Way accessible to us.

Distribution of Reflection Nebulae in the Milky Way.

The dots in Figure 15* indicate the positions of all objects in the

*Figure 15 does not appear in the Russian text.

catalogue in the new system of galactic coordinates. The figure also indicates the outlines of the dark clouds and other details whose significance will be discussed below. In examining this drawing, it must, of course, be kept in mind that with the exception of the nebula illuminated by Rigel, it is equally characterisitic of the distribution of reflection-nebula nuclei, since the nucleus-nebula angular distance is small. The drawing indicates that the nebulae show a distinct tendency to form more or less compact groups numbering from 3 to about 15 objects. No more than 10 - 15 solitary, completely isolated objects separated from one another by a distance of, say, 5°, can be counted. It must be acknowledged that the concentration of the nebulae into local groupings was noted even by Habbl [15] for both reflection and emission objects. Our material not only makes it possible to trace this tendency more distinctly, but also establishes certain new features in the distribution of the nebulae. First of all, stress must be given to an important if obvious consideration: these features emerge as a result of "superposition" of the apparent distribution of stars of spectral classes B1-A0 on the one hand, and clouds of absorbing matter on the other. However, available information is not equivalent for these two systems, since current data on the structure of the absorbing matter are inadequate and frequently contradictory. We shall have occasion to return to this question. On the whole, it is not difficult to discern the principal features inherent to the flat system of early stars in the distribution of reflection-nebula nuclei. Thus, along the galactic belt from Scorpius to Monoceros, we encounter the following known groupings or aggregates of hot stars, among which we may also include the corresponding pockets of reflection nebulae [21, 22]:

1. $l_{11} = 7°$, $b_{11} = -0°, 5$

The nebulae of the Sagittarius group, with the possible exception of No. 8, a "companion" of the Trifid Nebula, are situated in a region with strong absorption and dark lanes. This region emits in H_α. To some degree, the observed arches and filaments around the nebulae confirm that this is a single complex. The strong and nonuniform absorption makes accurate determination of the distance to the star impossible. However, if it is assumed that the nuclei belong to the main sequence and that absorption amounts, on the average, to 1^m per kiloparsec, we find that the distance to the complex does not exceed 100 parsecs. The nucleus of Nebula No. 82 belongs to the Sgr I association. /26

2. $l_{11}=56°$, $b_{11}=+3°$

The nebulae in Vulpecula and Sagitta are situated in the region of the Great Fork of the Milky Way. No close relationship among the individual objects of this group is observed. It is more likely that a projection effect is observed here.

3. $l_{11}=108°$, $b_{11}=+10°$

The nebulae of the Cepheus group form a large group of nebulae associated one-to-one with individual small clouds. The entire complex breaks down into two subgroups at 600 and 800 parsecs on the basis of the distances to the nuclei. In this case, it appears that we observe a cluster of small clouds extending from 600 to 800 parsecs.

4. $l_{11}=158°$, $b_{11}=-20°$

The nebulae of the Taurus group. All of the nebulae are situated in an extensive absorbing cloud. Estimates of the distances to the nuclei give values from 600 to 800 parsecs. Since accurate accounting for absorption is impossible and distance therefore cannot be determined, it may be assumed that the nebulae are at the same distance from us and form a single complex.

5. $l_{11}=201°$, $b_{11}=-0°,3$

The nebulae of the Monoceros group are situated inside a large cloud. Two of them (57 and 58) are in a narrow lane. The distance to the nuclei is 500 - 600 parsecs. It appears that both nebulae are associated with the same lane. Nebulae 60 and 61 may be more distant and belong to another cloud.

$$6.\ l_{11}=205°,\qquad b_{11}=-17°$$

The nebulae of the Orion group form a large group of nebulae composing the Orion complex. The average distance to them is 400 parsecs. The entire Orion region is saturated with dark emission clouds and reflection nebulae.

$$7.\ l_{11}=213°,\quad b_{11}=-12°;\quad l_{11}=215°,\quad b_{11}=0°$$

Nebulae of the Monoceros group. The first is an extremely close group of nebulae. The average distance to the group is 700 parsecs. Nebulae 53, 54, and 56 must be more distant, to judge from the magnitudes of the nuclei. However, the filament connections between the different nebulae indicate that they belong to the same complex.

$$8.\ l_{11}=238°,\qquad b_{11}=-3°$$

The Canis Major Nebulae (69, 70) apparently represent a single object with a nucleus ($\alpha = 7^h17^m.7$, $\delta = -23°57'$). The spectral classes of the other nuclei are unknown. Group 71 - 73 has nuclei of almost equal magnitude, and /27 the nebulae themselves are situated very close to one another in a single cloud. It appears that the group as a whole is the result of projection of individual clouds.

$$9.\ l_{11}=355°,\qquad b_{11}=+18°$$

The Ophiuchus-Scorpius nebulae are situated in a lane radiant. The average distance to the nuclei of the nebulae is 150 - 200 parsecs. The entire group forms the single Sco II complex.

$$10.\ l_{11}=142°,\qquad b_{11}=+3°$$

Group of two nebulae. The nuclei are members of the Cam I - II association ($\alpha_1 = 3^h25^m,0$, $\delta_1 = +59°46'$, *HD* 21191: $\alpha_2=3^h15^m,9$, $\delta_2=+58°42'$, *HD* 21389).

The centers of associations are indicated by crosses in Figure 15.

Basically, the features noted in the distribution of the much more numerous emission nebulae are repeated in the distribution of the reflection nebulae. Thus, on comparing the data given in Figure 15 with the corresponding data of G.A. Shayn and V.F. Gaze [23], which pertain to a somewhat narrower strip of the Milky Way, we find many of the groupings noted above among them. In either case, we observe a certain lacuna in the distribution at 30 - 55° of the Milky Way (Scutum-Aquila region).

There is no doubt that in many cases the emission and reflection nebulae are parts of the same hot-star physical grouping. The aggregate of stars and nebulae in Orion, the pockets of emission and reflection objects within small dark clouds, etc., can be cited as typical examples. Since the nature of the luminescence of both complexes is determined by the spectral classes of the stars, we may assume a high galactic concentration for the emission nebulae. Here, however, we are already touching upon more profound properties of the systems — properties governed by their origin, their relation to the spiral structure, associations and open clusters. Regarding the latter, incidentally, it should be noted that the differences between the complexes are not so obvious: According to certain sources, approximately 1/6 - 1/7 of the emission nebulae are associated with open clusters [24], and it appears that the same proportion is preserved for the reflection nebulae, some of which are associated both with known clusters and with close star groups. The same type of correlation is observed for other objects in "local groups". The deviations from it sometimes have obvious explanations. Thus, in the most numerous and extensive complex near Cygnus ($l_{11} = 80°$, $b_{11} = 0°$), which contains several dozen emission objects, there are only three reflection nebulae. At the same time, it is known that precisely this complex is distinguished by strong anomalies in the number and distribution of hot stars [23].

In his day, Habbl [15] drew attention to the concentration of some of the diffuse nebulae along the Gould belt. It is known that the local system of bright (mainly no fainter than $5^m.5$) B-stars close to the Sun is associated with this effect. The nodes of the belt have the coordinates $l_{11} = 120°$ and $b_{11} = 300°$ [25], so that the bright B-stars should be situated south of the galactic equator along the galactic belt between longitudes 120 and 300°. Something similar to this is registered in Figure 15. Here, near $l_{11} = 120°$, we note one of the nodes indicated and asymmetry in the distribution about the equator. However, it must be remembered that there are no more than ten nebulae associated with bright stars of $m < 6$. At the same time, several tens of fainter stars testify to the asymmetry phenomenon. /28

Figure 16 shows the distribution of the number of nebulae over the apparent magnitudes of their nuclei. As we see, the histogram has two characteristic maxima. Figure 16 simultaneously confirms that there are few bright stars down to $m < 7$ inclusive. However, it follows from many studies based on hundreds of B stars that all traces of the local system and perhaps even of the Gould belt have disappeared even for $m = 7$. However, our much less numerous data permit (or, in any event, do not contradict) interpretation of the features of Figure 15 on the basis of a relation to the local system. The possibly clearer indication of the local system by the reflection nebulae is explained by the fact that it includes both B stars and dark clouds. There are references to correlation between B8-B9 stars brighter than magnitude 6.5 ($b_{11} < 50°$, $r < 200$ parsecs) and dust clouds [26] and to the absence of any discernible connection with dense hydrogen clouds in the case of faint B stars [27]. The last-cited study was based on a comparatively modest volume of material and the author regards it as preliminary. It appears to us that the available data are insufficient to explain the general features of the reflection-nebula distribution in connection with the structure of the Galaxy. /29

It follows from Figures 15 and 17 that the apparent concentration of the nebulae along the Gould belt is due chiefly to the complexes of objects in Orion and Scorpius. Both are extremely young formations, and their inclusion into the local system should be governed by its evolution and relation to the spiral structure, since the aggregate of stars in Orion apparently represents the nearest part of the "Orion arm" [28], etc. Unfortunately, most of the stellar-astronomical and dynamic properties of the local system have not yet

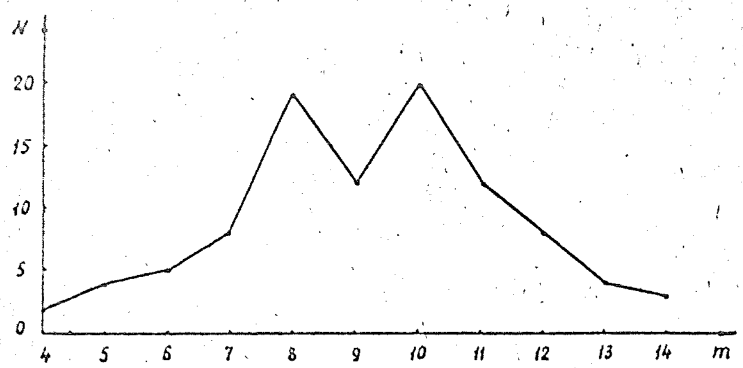


Figure 16

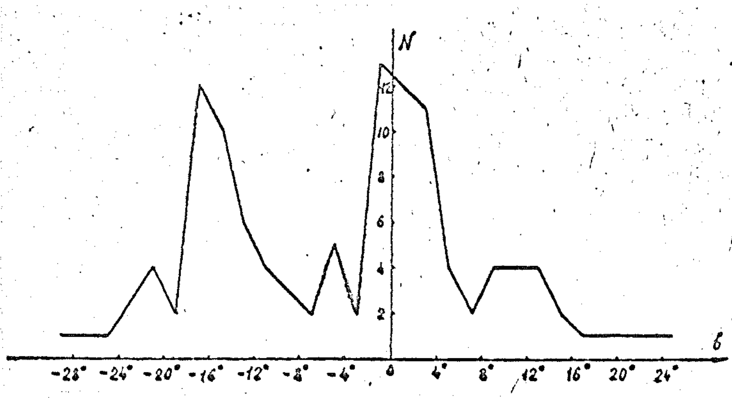


Figure 17

been thoroughly studied. Nor may we omit mention of another possible interpretation of the phenomenon discussed here. On the basis of study of polarimetric data for stars studied, on the average, at distances no greater than 1,000 parsecs from the Sun, G.A. Shayn inferred the existence of a local condensation of early stars and dust and gaseous matter that appears to be different from the Gould belt, i.e., from the local system of bright B stars. G.A. Shayn includes the gas and dust complexes in Scorpius, Sagittarius, Taurus, and Orion in the local condensations [29].

It is difficult at this time to choose between these two possibilities and include all reflection nebulae or some of them in one of the above systems.

Returning to Figure 16, we can explain the appearance of the first maximum in the nebula distribution by attributing it entirely to the complex of nebulae in the Orion region. The second maximum with the mode m = 10 should be attributed to objects that are associated approximately uniformly with the galactic equator.

Figure 18 shows the distribution of the nebulae among the spectral classes. It must be noted that these data are known only for 80-odd objects, which are usually no fainter than the 10th or 11th magnitude. Some of the spectra have been classified from photographs made with a 6-degree objective prism by Yu. I. Glushkov and one of the authors.

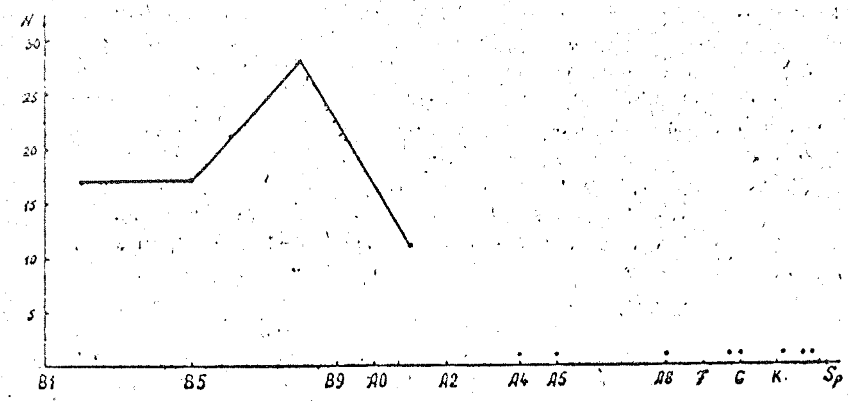


Figure 18

Thus, we have reason to assume as an average characteristic for the population of reflection-nebula nuclei

$$SpB\,7\,V, B = 9^m,\ r = 500 \text{ par sec},$$

if we take $M_V = -0^m.5$ according to [30] and an absorption Apg $\simeq 2^m$ per kiloparsec. These data probably characterize quite closely no fewer than half of the nuclei in our Catalogue.

Reflection Nebulae and Absorbing Clouds. /30

The apparent distribution pattern of dark clouds in the Milky Way belt is shown in Figure 15 after Lynds. Lynds drew it up on the basis of a study of dark clouds on individual "two-color" reproductions of the Palomar Atlas. We made reference above to possible inaccuracies and simple errors in drawing the contours of the clouds and estimating their densities, especially in such extremely complex and confused cloud systems as are observed in the Sagittarius region. Nevertheless the pattern is, on the whole, not lacking in objective content. Even before Lynds, Khavtasi [31] made a similar investigation using the Ross-Calvert and Barnard Atlases. There are still earlier studies of specific regions of the Milky Way that pursued the same basic objectives.

On the whole, the authors arrive at similar apparent distribution patterns and similar general outlines for the dark clouds on the basis of their differing methods and sources. There are, of course, inevitable discrepancies in the interpretation of the complex cloud systems and fine details, but these are not crucial to our problem. It must be noted that the reproductions from the Palomar Atlas have many advantages over the other sources, so that the data of Lynds probably carry greater weight. Our Figure 15 does not include numerous small clouds referred to in the Lynds catalogue. This drawing is of interest primarily from the standpoint of the apparent general relationship between the complex of nebulae and the complex of clouds. The close similarity in the distributions of the two complexes about the galactic equator is established beyond a doubt, since both show north and south asymmetry and a "node" in the region of l_{11} = 120 - 160°. The similarity becomes clearer if we compare the distribution of the "centers of mass" or densities of the clouds with the distribution of the centroids of nebula groups obtained by averaging their coordinates in each 10-degree longitude interval.

In Figure 19, the positions of the former are indicated by crosses after Lynds. The circle indicate the positions of nebula centroids. We see that after such averaging, the pattern enables us to divide the entire complex of clouds and nebulae into two major groups situated on different sides of the equator and merging into one another near l_{11} = 150°. The asymmetry in the dark-cloud distribution, which has been confirmed by radio observations [32], is usually ascribed to concentration of part of the absorbing matter in the Gould belt, of which we spoke above. It appears to us that this question is not yet definitely resolved, since objects that belong to the spiral arms, specific accumulations of gas and dust at higher galactic latitudes [33], etc., participate in the asymmetry phenomenon. At the same time , it is interesting that very broad nebulae of very low surface brightness can apparently be associated with B5-B8 stars no fainter than the sixth magnitude. More than a score of these objects can be indentified on the high-contrast reproductions of the Palomar Atlas. They are usually faint, rather broad arches or shells extending over 2 - 3° and, as a rule, observed in the vicinity of groupings of several generally bright stars of the later B classes. On our summary chart (Figure 15), the center positions of these nebulae are indicated by squares.

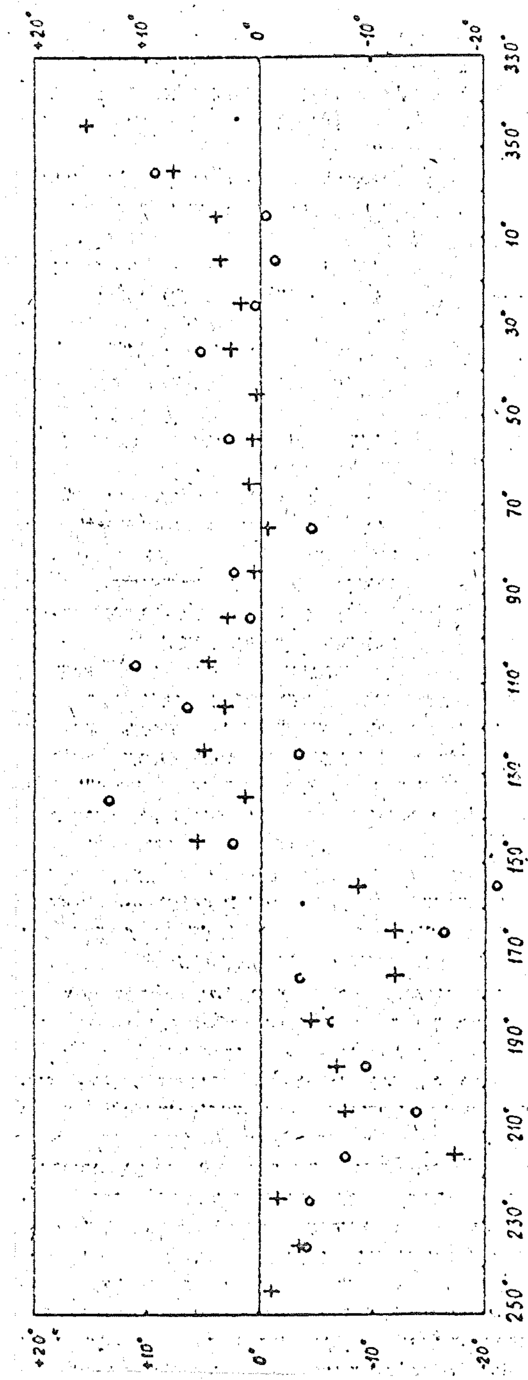
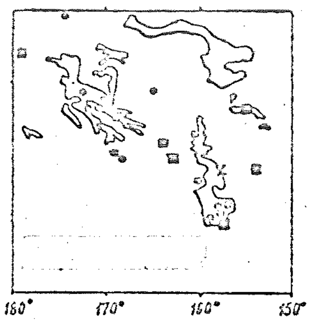


Figure 19



Emission nebulae

Reflection nebulae

Figure 20

We see that, unlike most ordinary reflection nebulae, /32 they are all concentrated at a considerable distance from the equator. This can be explained by their nearness to the Sun and by the less favorable visibility conditions at low latitudes, where these faint objects are projected against the brighter background of the Milky Way. Interesting features of these nebulae are their almost identical brightnesses on the O- and E-reproductions of the atlas and the fact that it is impossible in most cases to associate them with clouds of absorbing matter.

The origin of these objects is not yet entirely clear; specifically, the role of hydrogen emission in their spectra is unknown, since the nebulae often lie outside the Stromgren zone corresponding to the spectral classes of the neighboring stars. It is possible that these nebulae represent former H II regions now in a state of de-excitation. Whatever the case, this group of nebulae is interesting and deserves a special study.

Returning to our discussion of Figure 15, we may nevertheless affirm that, on the whole, there is no preferential relationship between the reflection nebulae and the very broad absorbing regions of the Milky Way according to the large-scale details of the drawing. Thus, there are relatively few of them in the Sagittarius region, which is crossed by numerous dark clouds that are probably close together. In general, the pattern may be characterized as follows. Somewhat less than half of all the nebulae are concentrated in the large clouds and complexes of large clouds, which, incidentally, occupy about 1/3 of the sky area (Figure 15). At the same time, whole groups of nebulae experience attraction to precisely these broad clouds in a number of cases. We include among these the nebulae of the Scorpius-Ophiuchus, Taurus, and, finally, the Orion groups, where their relation to the clouds of interstellar matter is regarded as genetic on the basis of contemporary data.

The common features noted in the distributions of the dark clouds and their nearby reflection and emission nebulae in the region of $l_{11} = 165°$ and $b_{11} = -10°$ is interesting and perhaps no accident. This is represented separately on Figure 20; here, the points represent reflection objects and the square emission objects (according to Shayn and Gaze).

Using the results of more detailed study of the relation between the individual nebulae and the structure of the absorbing matter visible in their vicinity (see Figures 3 - 10), we may draw the following conclusions: in no fewer than 80% of cases, the reflection nebulae are visible within sharply outlined, isolated dark clouds. It might be thought that we are observing, in most cases, a quite spatial and not an apparent "optical" connection between the reflection nebula, or more precisely, its nucleus, and the corresponding dark cloud, part of which is illuminated by the nucleus. This statement is based primarily on certain structural-morphological properties of the objects studied as seen directly on photographs. The most signficant of these properties will be of interest (Figures 3 - 10)[1].

1. Over a certain distance, the boundaries of the absorbing cloud coincide almost exactly [with] or conform to the apparent boundary of the reflection nebula. A typical case is the nebula around the star ν Scorpii (Catalogue Nos. 75 and 107). Sometimes the cloud boundary coincides with a faint luminous ionization front ("rim"), near which the reflecting nebula is situated (Catalogue No. 16). /33

2. The nucleus, together with the nebula surrounding it, lies next to a very dense dark condensation of the globule type. A highly characteristic example is Catalogue No. 20. Often, this entire system is, in turn, situated in the densest part of the cloud. In general, relation to globular inclusions is a quite common phenomenon among the nebulae of small angular diameter. This same type of relationship with clouds is characteristic for nebulae that are divided into two parts by a dense, dark bridge.

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[1] The Catalogue numbers of the nebulae are given in the circles in the upper right corners.

3. The nebula is situated at the end of a dark lane or system of lanes, almost always in the densest round expanded part. The origin of the lane or lanes opens out into a complex system of branches or gradually fades out.

The known large nebulae around ρ Ophiuchi[2], ν Scorpii, and others lie in lane junctions. A similar case can be seen in the structure of the clouds south of the filamentary nebula IC 1287 (No. 92), and certain others.

Single lanes with "blind" terminals containing one nebula or even a group are more characteristic. We observe this in the following objects: NGC 7023 (Catalogue No. 105), IC 5146 (Catalogue No. 114), Ced 201 (Catalogue No. 117), and the Anonymous Nebula (Catalogue No. 118).

Nos. 20, 25, 47, 58, 64, and others are less characteristic. They include nebulae situated in branches or "capes" or dark clouds.

It is interesting to note that certain lanes exhibit visible luminescence over a considerable length. The causes of this phenomenon and the probable sources are not quite clear to us. Sometimes the luminescence is more intense in red light, including an H_α line. We cannot exclude the possibility that such lanes are H II regions in de-excitation, of which we spoke earlier[3].

4. Approximately one-quarter of the objects in our catalogue are nebulae seen in a region of closed clouds whose boundaries can be traced out quite reliably. Figure 21 gives a comparison of the magnitudes of the nebular nuclei with the areas of the clouds (in square minutes of arc) in which they are situated. As we see, the relationship reduces to a certain scattering field of the points with its center near m = 9 and S = 500 square minutes. Assuming, as before, an average distance of 500 parsecs to the nebulae, we obtain an estimate

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(2) According to P.N. Kholopov, this star is the center of a T association [21].

(3) The general radiation field of the stars of the Galaxy may also be a source of luminescence.

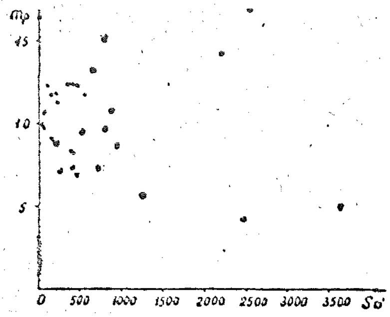

Figure 21

of 3.5 parsecs for the average cloud diameter. This result is somewhat on the low side as a result of selection. According to radio observations, the average dimension is of the order of 10 parsecs [33]. However, the same average dimension has recently been obtained from the color excess of 4700 stars [34]. In certain cases, this estimate can serve as a rough criterion for judgements as to the reality of physical relationships between reflection nebulae and their clouds. One of the points in Figure 21 (which corresponds to a 14th-magnitude nucleus) is a /34 good example; its position deviates widely from those of the other points. The possibility is not excluded that this nebula is merely an "optical" companion of the corresponding cloud. Such cases are, however, quite infrequent. In general, the maximum distance at which a nucleus can illuminate a given cloud depends not only on the luminosity of the nucleus, but also to a substantial degree on the shape of the dust-particle scattering indicatrix.

In principle, reflection nebulae in the form of faint aureoles might be observed around certain supergiant stars at distances of 100 - 200 parsecs behind absorbing clouds. However, the average size of the dust particles in such clouds would have to be considerably larger than would follow from the observational data, and especially from the polarimetric properties of the reflection nebulae. The partial polarization observed in them, which is usually radial with respect to the nucleus, indicates a sparial relationship between the nucleus and the dust medium of the clouds. However, the decisive argument in favor of this proposition is, of course, the previously noted fact that the overwhelming majority of nebulae are located within the definite boundaries of the dark clouds identified with them on photographs. In this context, we can see the following data that characterize the observed phenomena.

SITUATION OF NEBULAE	NUMBER OF NEBULAE
Within cloud	41
On boundary of cloud	25
Within lane	3
On "edge" of lane	12
At end of lane	15
No apparent relation with absorbing medium	22

These data can be obtained directly from the sketches (Figures 3 - 10) that accompany the catalogue. They do not imply that cases in which several (up to ten) reflection nebulae can be counted in a single cloud are infrequent. The picture would be substantially different in the absence of a physical relation between the objects. For example, "empty" clouds with groups of nebulae unrelated to absorbing material beyond their boundaries would be observed.

Certain studies refer to higher concentrations of weak variable and emission stars toward the margins of dense dark clouds [35]. As we see from the figures (Figures 3 - 10), something similar can be discerned among the reflection nebulae. However, this trend still does not appear quite distinct. An attempt was made to verify the reality of this phenomenon from 20 more or less round isolated clouds that contain about 60 nebulae. The result is represented in graphical form (Figure 22). The distance (ρ) of the nebula from the center of gravity of the cloud, expressed as a fraction of the radius of the circle having the same size as the cloud, was plotted against the horizontal axis, and the number (n) of nebulae corresponding to these distances against the vertical axis. We see that in general, n and ρ are linearly related; this would rather /35
tend to indicate accidental positioning of the nebulae within the clouds. Needless to say, such statistical figuring is not applicable for lane-like clouds and clouds with "capes", where cases of distinct concentration of the nebulae toward the boundaries are observed at once.

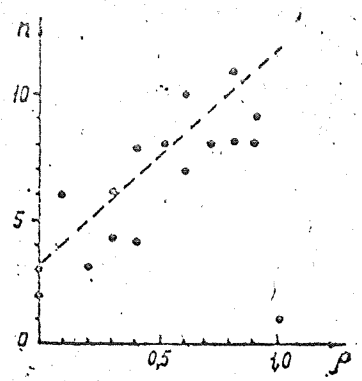

Figure 22

5. We touched above upon the question of local groups into which the complex of reflection nebulae can be decomposed. Here we had in mind the large-scale features of the apparent distribution of the nebulae in the Milky Way. There are few such groupings, and it may be that not all of them are genuinely real, i.e., consist of spatially related objects.

At the same time, the tendency toward formation of various types of groupings is indeed found to be more common among reflection nebulae. This conclusion can be arrived at as a result of more detailed study of objects present on the same areas of the sky that are occupied by reflection and, less frequently, emission nebulae. A survey of our photographs and the Palomar Atlas reproductions (here, certain details are often masked by the excessive emphasis on contrast) enabled us to identify about 30 cases in which such a tendency appears in one way or another. We did not include a number of objects in the Orion region among them, since they definitely belong to known physical groupings. It should be noted that the groupings singled out can be identified with known open clusters in only three or four cases. The Pleiades group of reflection nebulae must, of course, be included here.

The phenomena observed in the 30 cases noted can be reduced to two basic types:

(a) the reflecting nebula is distinctly united with a star cluster;

(b) the reflecting nebula is seen together with a close group of minute nebulae (often with a C + E spectrum).

The distinctions between these two types are at times arbitrary, as when a complex nebula is illuminated by a group of nuclei that compose a cluster or when the nuclei themselves (no fewer than four) form a close grouping.

At this time, we do not yet have systematic data on the properties of the "population" making up all the groupings; nevertheless, references to relationships between specific reflection nebulae and various types of peculiar stars can be found in certain sources. For example, about twenty flare stars have been found in the vicinity of the nebula NGC 7023 (Catalogue No. 105) [17], and the nebula NGC 2068 (Catalogue No. 42), which exhibits many "anomalous" features, has no fewer than ten "companions" in the form of Herbig-Aroult objects [36].

The Anonymous Nebula (Catalogue No. 114) is a typical reflection nebula situated in the neighborhood of the known emission nebula IC 5146 (which is, /36 strictly speaking, a nebula with a composite type C + E spectrum). There are several dozen Herbig-Aroult objects around it [37]. This entire system lies at the end of a "blind" lane.

NGC 1333 (Catalogue No. 12) is a typical reflection nebula illuminated by two nuclei; a chain of minute emission condensations appears in the vicinity. According to M.V. Dolidze, there is one star with emission among the objects visible in the neighborhood of this nebula [8]. According to the same author, emission stars are observed in the vicinities of several other reflection nebulae or C + E objects. It is appropriate to note that several dozen flare stars are members of the clusters in the Pleiades [38]. According to preliminary data, at least half of the 30 groupings noted above may be related to various nonstationary objects. It should be remarked in passing that variables can be identified in the same clouds that are tenanted by 57 nebulae of the Catalogue. They contain a grand total of about a hundred variables [39], many of which are of the RWn type. The attraction of stars of this type to dark clouds is well known and can, of course, be regarded as a phenomenon that is totally independent of the complex of reflection nebulae. Distinct groupings of nonstationary objects represent an exception that we shall discuss below.

The nuclei of certain reflection and C + E nebulae also exhibit variability. The most characteristic objects are the following:

CATALOGUE NUMBER	STAR	TYPE
17	RY Tau	RW n
20	AB Aur	RW n
34	N 6361 CSP	?
106	N 8645 CSP	E II

Reflection Nebulae and the Relation Between Stars and Absorbing Matter.

The question as to the nature of reflection nebulae was, as we know, first considered by V.A. Ambartsumyan and Sh. G. Gordeladze [40]. Statistical analysis of observationa data enabled these authors to conclude that these objects arise as a result of random association of stars of a suitable spectral class with dark clouds. Strictly speaking, V.A. Ambartsumyan's investigation was concerned with solution of a more general problem — whether the association of stars with absorbing matter of our Galaxy is accidental or not. Reflection nebulae can be regarded as a side effect, as a kind of indicator to the number of observed cases of association. More than two decades have passed since publication of these researches, and during this time the observational data in this field have naturally been supplemented and expanded. But does this imply that earlier notions as to the nature of the relation between the stars and the interstellar medium must be radically revised? A discussion of this problem, which is related in one way or another to the evolution of the stars and the interstellar medium, would be far beyond the scope of our problem. Indeed, presently available data would hardly permit us to advance any generally acceptable conception in this area.

It will be appropriate to limit ourselves here to certain considerations /37 with a bearing on the relationships between reflection nebulae and dark clouds as they would appear on the basis of their properties. Even in this formulation, the problem is apparently quite complex.

There is no reason to doubt the existence of the "classical" reflection nebula, which was formed by accidental penetration of a class B3-A0 star into a dark cloud. Probably no fewer than half of the objects in the Catalogue are nebulae of this type. We should add that these nebulae exhibit no peculiarities as regards emission structure or relation to dark clouds and groupings of other objects. In any event, we have no additional information that would cast doubt upon the "classical" origin of the nebulae of this group.

There follows a comparatively small group (about 10) of nebulae whose situation in dark clouds contradicts the accident hypothesis to one degree or another. These are for the most part nebulae visible at the ends of dark lanes, and then in "capes" of large clouds. Unfortunately, it is difficult at this time to propose any reasonable alternative mechanism that would explain this curious effect. It may not be possible to find any single mechanism at all, since the objects in such clouds have various physical characteristics. We encounter normal class B8-A0 stars, emission stars, and finally, type RW Aur variable stars among them.

Each of these cases presents specific difficulties of explanation. We might, for example, advance a purely geometrical interpretation: the nebulae are in fact located at the bend of an L-shaped lane, one "arm" of which is in the line of sight. However, this hypothesis is still difficult to reconcile with the observed structures. For the case of Ced 201 (Catalogue No. 117), we might suspect some sort of condensation process (for example, the "mysterium" on graphite nuclei) that took place while the star was in motion and was accompanied by formation of absorbing matter in the form of a "track". Evidently, this hypothesis will come up against numerous difficulties, foremost among which is the fact that it stands in contradiction to the spectral properties of the star.

Difficulties are also encountered in attempts to use other explanations, for example, the existence of a "galactic wind" that compacts the frontal parts of the clouds, explanation of the lanes as "elephant-trunk" residues, by the local-magnetic-field hypothesis, and so forth. Here problems arise in connection with the need to explain the history by which the "lane" originated, linking it to the prior history of the star. Other difficulties, which are to some extent related to those just described, consist in the fact that the objects belong in different groupings. Among them, we encounter both ordinary reflection nebulae and nebulae with luminescence and structural peculiarities. How did these groupings, with their preferential associations with dark clouds, arise? It is known that not even the Pleiades are an exception to this rule [38]. Is the relation of the groupings with the dark clouds within which they are observed an accident? We know that some of them include nonstationary objects of the T Tauri type, as well as Herbig-Aroult objects. The genetic link of the former with the dark clouds in which they are observed is now no longer /38 in doubt. However, except for a few cases, we have no data as to whether a reflection nebula (or similar object) is indeed some kind of physical member of the grouping.

The luminescence of the nebulae often exhibits properties that are, on the whole, difficult to reconcile with the properties of the typical reflection nebula. However, before going into the subject of anomalies, it will be necessary to clarify what we mean by the luminescence of a typical reflection nebula. It is usually assumed that its spectrum is basically identical to that of the nucleus. But it is precisely this property that has the weakest observational basis. Moreover, even in the spectra of "typical" nebulae, we observe more or less pronounced differences from the spectra of the nuclei corresponding to them. (For example, in the nebulosity surrounding Merope; see the article by Yu. I. Glushkov in this issue.) It might be supposed that a spectrum that does not resemble the reflected spectrum closely enough is characteristic for nebulae associated with low-density clouds. Basically, these nebulae are distinguished by very low surface brightness and present great difficulty for spectral observations, chiefly becuase of the interference introduced by the skyglow. In denser clouds, the surface brightness of the nebulae is, on the average, higher, but even here the various deviations from the purely reflective mechanism of spectrum formation are beginning to make their appearance.

Thus, all forms of anomalies can be traced among the objects composing the Orion complex of stars and nebulae. Here, together with the comparatively few pure reflection nebulae, there is a more numerous group of objects with the C + E spectrum. Their illuminating stars usually belong to the early B spectral classes, although certain objects are associated with peculiar stars of later types and, like FU Ori, have their own peculiarities [41].

A general survey of certain normal C + E nebulae was made at one time at the Crimean Observatory [42], and there is no need for us to go into the various details of this question. The basic result of the work, in our opinion, can be stated thus: the observed relationship between the C- and E- components in the luminescence of the nebulae is determined, apart from the spectral properties of the nucleus, by the varying proportions of gas and dust present in them. This conclusion is quite convincing and consistent with more detailed observations, although certain recent studies have advanced somewhat different reasoning concerning the gas/dust relationships in the matter of diffuse nebulae [43]. To all appearances, the interest of these objects is by no means exhausted by investigation of their luminescence properties alone. It is no less imporant to know whether their luminescence depends on a random distribution of dust and gas in the space surrounding the nucleus. We feel that this problem has not yet been thoroughly explored. Observational data are still inadquate, and little is known of the physical conditions in dense gas-and-dust clouds.

It should be noted that purely random causes can be assumed for the formation of the C + E spectrum in the case of the familiar nebula AE Aur, as well as possible differences in the spatial structure of the gaseous and dust materials [44, 45]. However, if we return to the nebulae of the Orion region, all /39
we can point to here is a certain sequence in the properties of the C + E objects that depends on the spectral class of the nucleus.

(a) The luminescent dust component of the structure is apparently (and, very probably, spatially as well) sharply different from the corresponding emission component. The density of the gas and dust is low. IC 432 is a typical example. An analog of this nebula is the object

BD + 8°933 (Catalogue No. 22), whose gas and dust components are also of low density. Such nebulae are illuminated by B stars of the later classes.

(b) The internal parts of the dust and gas components of the structure differ only slightly; dust luminescence predominates in the outer parts. Nuclei of the earlier B0-B1 spectral classes would appear to be characteristic for this type. In this respect, the nebulae NGC 2023 and NGC 2068 are analogs of IC 5146.

(c) The dust and gas components of the structure do not differ substantially over the entire area, but dust luminescence is nevertheless noted at somewhat greater distances from the nucleus. The nebula excited by ζ Orion is a typical object. This property is also discerned in the strongly emissive nebula M8 (the Trifid). The Great Nebula in Orion can also be referred to the latter case.

In these last two cases, the dust and gas densities are substantially higher than they were in the first. For most C + E nebulae, the radial velocities of the nuclei and their H II regions remain unknown. Only for the Trifid and the Great Nebula in Orion do we know that the radial velocities of the nebula and nuclei are closely similar in absolute magnitude and of the same sign. It is difficult to say whether the luminescence and structural peculiarities noted for these nebulae reflect different stages in the evolution of their nuclei. It may be that the homogeneity of the dust/gas mixture is determined basically by the internal-energy store of the gas, since this quantity characterizes the ability of the gas to entrain dust particles as it moves. In our view, the questions as to how this energy depends on star spectral class and what are the properties of the dust particles in such nebulae have not yet been resolved satisfactorily.

As we noted at the beginning of this section, we have no basis for linking the question as to the origin of all reflection nebulae directly with the more general problem of the evolution of the stars and the interstellar medium.

However, it appears to us that in certain cases the possibility of such a connection cannot be ignored, regardless of the viewpoint from which we undertake to discuss the properties of these objects. Thus, for example, we might regard them as a source of certain additional information on the physical properties of interstellar dust particles over and above that usually obtained from observations of the interstellar attenuation of starlight. It is the data obtained from just these observations that indicate marked variations in the properties of the absorbing matter associated with various groupings of hot stars. There are many reports to the effect that similar phenomena are observed in small condensations of the interstellar medium, which contains emission nebulae, open clusters, etc. [33]. Some of them can be explained by such local factors as general and local magnetic fields, the spiral structure, the radiation pressure of hot stars, and the like. It is possible that the diffuse matter itself has survived an earlier evolutionary stage in such regions of the Galaxy as the Orion region, with its strong anomalies in the behavior of the interplanetary dust particles. We know that the ages of the various star groupings in Orion are estimated at 10^4 - 10^6 years, so that many young stars still retain their /40
spatial connections with the local diffuse medium. Unfortunately, we do not know the ages of the stars related to the reflection nebulae and kindred formations that are typical for this region. We might suggest 10^5 years as a probable figure. If the Orion objects are taken as a kind of standard for nebulae illuminated by young stars, then what can be said of the other nebulae seen in dark clouds and situated in other regions of the sky?

We have already made reference at various points in our survey to certain interesting peculiarities of a number of nebulae that do not belong to the Orion group. The following remark is appropriate here: all properties of the Orion nebulae with a bearing on luminescence and structure are to some extent characteristic for scattered objects found in individual dark, dense clouds. From them, we exclude such definitely peculiar nebulae as the cometaries or those related to T Tauri stars, since it appears highly probable that they have a common nature anyway. We are concerned with nebulae that are instead associated with normal stars, to the extent that this can be judged from available data. In referring to structural similarity, we refer, of course, to characteristic details presented by dense globules embedded in the luminescent material of the nebula and by other dark inclusions, sectioning of the nebula by a dense absorbing bridge, etc. Curiously enough, the similarity of structures is sometimes very clearly manifest. Thus, for example, a small nebula (Catalogue No. 25) is highly similar in a number of criteria to the brightest nebula, NGC 2068. In regard to luminescence, the objects under discussion form a sequence characterized by the same emission and continuum properties as are observed in the nebulae of the Orion group.

It can be calculated that for an average dark-cloud size of 3 - 4 parsecs and a velocity of the nuclei with respect to the clouds on the order of 10 km/sec, the time of residence of the star in the cloud is about 10^5 years. As we have noted, it is possible that this interval is important for the Orion-type nebulae. We feel that it would be premature to draw any serious conclusions from this line of reasoning for extension to other objects, since we know neither the properties of the absorbing matter in the dense clouds nor the visible characteristics of most of the stars associated with them, etc. The analogies to which recourse must be taken, beginning with the objects in the Orion clouds and ending with objects in other clouds, pertain for the most part only to the "surface" of the observed phenomena. We have repeatedly stressed the inadquacy of such data as a means of clarifying the interaction between the stars and the dark clouds. However, many observed cases of association between stars and nebulae are difficult to explain simply in terms of "mechanical mixing" of the stellar and diffuse matter of the Galaxy.

We suggest that nebulae that are of interest in this sense be isolated into a special group. A program must be drawn up for further study of these objects, and should include the following questions:

(a) Acquisition of more detailed and complete data on the spectral properties of the nebulae and their nuclei, since the available determinations of spectral classes, luminosities, and distances are most inadequate and often contradictory. There are almost no spectral observations suitable for comparison of the radial velocities of the nuclei and /41 the nebulae that they illuminate. Our information on the variability and nonstationarity of many interesting objects is inadequate.

(b) Explanations must be sought for certain relationships observed in the positions of nebulae inside dark clouds. Such a problem arises in connection with the "anomalous" luminescence of nebulae situated in dense dark clouds.

(c) The nature of the groupings formed by nebulae and star clusters associated with nebulae must be established.

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